WATER QUALITY ANALYSES OF THE COLORADO RIVER CORRIDOR OF GRAND CANYON

by

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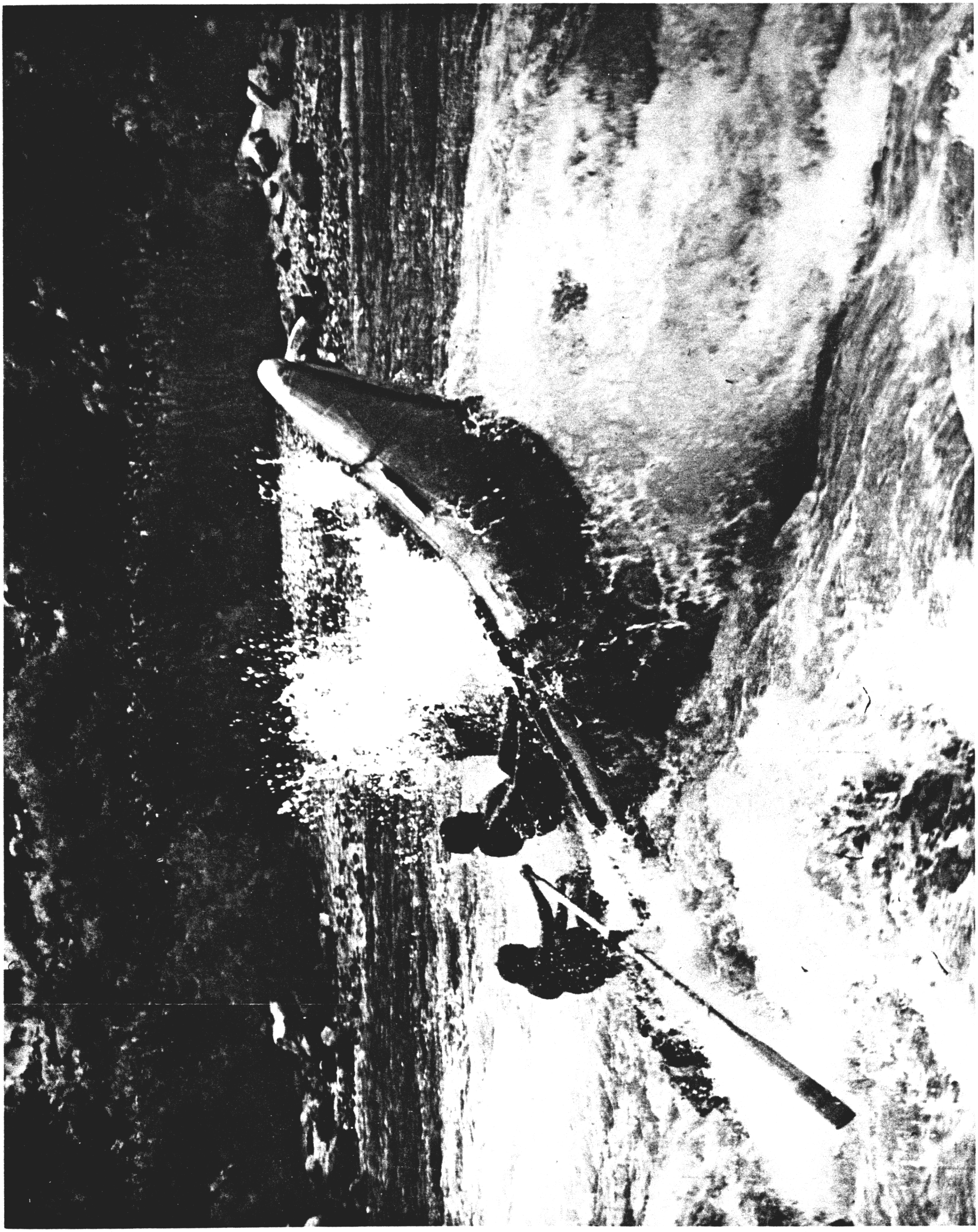
SECTION I

RESEARCH SUMMARY



I. RESEARCH SUMMARY

Water Quality Analyses of the Colorado River Corridor of Grand Canyon documents baseline water quality studies of the Colorado River and tributaries. This report is written to provide resource agencies and river runners with a perspective of water quality status as it relates to river running activities. Specifically, the research is problematic of Grand Canyon, but many of the findings have broad implications for other white water recreational rivers. This document is divided into five sections: I. research summary, II. research introduction, III. research methods, IV. data presentation, and V. discussion, conclusions, and recommendations.

A. RESEARCH PURPOSE

Water quality analyses in Grand Canyon examined Colorado River and tributary baseline water quality status in relation to recreational float trip use of the river corridor. Float trip use of Grand Canyon has increased over recent years (since 1966) to levels which have caused concern for water quality-river running associations. River runners have traditionally used the Colorado River and tributaries as sources of drinking and cooking water, for swimming and bathing, and, at times, as a disposal for some refuse, e.g., dishwater and leftover food. Associated with float trip use of the river corridor water resources has been potential water quality hazards. During the 1972 and 1979 float trip seasons (May through September) outbreaks of gastroenteritis* occurred among river runners in Grand Canyon, prompting investigation by the Center for Disease Control, Atlanta, Georgia; an enteric pathogen *Shigella sonnei* was isolated from some river-trip participants. Potentially, the Colorado River or a tributary served as a source or carrier of the pathogen, though this has not been confirmed. Enteric disease organisms excreted in feces by humans, wildlife or domestic animals can become potential sources of infection; water contaminated with fecal organisms can distribute diseases.

The purpose of this study is to develop baseline profiles of the water quality status of the Colorado River and the confluent reaches of

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*Gastroenteritis is one of several diseases of the stomach and intestines caused by one of a number of enteric pathogens; associated symptoms include diarrhea, nausea, vomiting, headache, and weakness.

its tributaries within Grand Canyon. Results of the study will serve as a reference for National Park Service management policies for Grand Canyon and as a basis for future research of Grand Canyon and other white water rivers.

B. RESEARCH APPROACH

Water quality analyses of the Colorado River corridor occurred during the 1978 and 1979 river running seasons. Examination of the extensive river corridor necessitated analyses in the field. Travel through the Grand Canyon was via research rafts in a series of six float trips, April through September, in 1978, and two float trips, July and August, in 1979; 82 field days in 1978 and 22 field days in 1979.

A total of 497 water quality samples were collected over two seasons from the Colorado River along the 225-mile stretch from Lees Ferry to Diamond Creek, the launch and take-out points of the research trips. The confluent reaches (within approximately 200 yards of the Colorado River) of 26 side creeks in the river corridor were also sampled in 1978; nine tributaries were sampled in 1979. Additional samples collected from upstream locations on some side creeks increased the tributary sample site total to 33 in 1978 and to 13 in 1979 for a two season total of 215 individual tributary samples.

Selected microbial, physical, and chemical parameters were measured to determine baseline water quality status in the Colorado River corridor of Grand Canyon. Research emphasis was on microbial water quality; physical and chemical parameters were measured to facilitate evaluation of the microbial profiles. Microbial parameters included fecal coliform (FC) bacteria and fecal streptococcus (FS) bacteria densities; physical parameters included turbidity and water and air temperature; chemical determinations included alkalinity, hardness, phosphate, nitrate, chloride, total dissolved solids, and pH.

FC bacteria and FS bacteria are groups of enteric indicator organisms which occur naturally in the digestive tract of warm-blooded animals, are nonpathogenic, and are excreted from the body in fecal matter. Concentrations of these bacteria groups in water are proportional to a probability of enteric pathogens also being present, indicating a water quality hazard. FC bacteria predominate among human enteric organisms and FS bacteria predominate among enteric organisms of nonhuman warm-blooded animals; the relative ratios of the densities in water of the two bacteria groups is indicative of the probable source of fecal contamination, human or nonhuman. Federal and state water quality standards for recreational waters are based on FC densities, i.e., 200 FC/100 ml for full body contact and 1000 FC/100 ml for partial contact.

Enteric organisms can be found in the water column and underlying bottom sediment of natural aquatic environments. Traditionally, recreational water quality studies are limited to analyses of surface water densities of indicator organisms; bottom sediment concentrations of enteric organisms are rarely examined or even recognized as critical factors in determining the overall water quality status of a recreational resource. Overlooking bottom sediment water quality considerations can lead to false conclusions regarding recreational water quality status. Bottom sediments are a microbial habitat where enteric organisms can persist and concentrate, representing a significant latent potential to degrade surface water microbiological quality is resuspended by currents, wave action or recreational activities (Van Donsel and Geldreich, 1971; Hendricks, 1971; Motschall, 1976; Winslow, 1976; McKee, 1977; and Morse, 1979).

University of Arizona research in Grand Canyon examined FC and FS densities in Colorado River and tributary surface waters and FC densities in river and tributary bottom sediments. Surface water bacteria densities were determined in the field using membrane filter (MF) methodologies for microbiological analyses; MF techniques were adaptable to field research procedures. Bottom sediment bacteria densities were determined by two variations of the most probable number method (MPN), a multiple fermentation tube technique which was not readily adaptable to field research. In 1978, a technique of storing bottom sediment samples intact on ice for up to 14 days was developed and successfully tested and used. Bottom sediment samples collected in the field were stored on ice until transport out of the Canyon to a laboratory for MPN analyses. For the 1979 research phase, the MPN methodology and apparatus were modified to allow in-the-field analyses.

Sample designs for the Colorado River and tributaries were distinct. Two designs were employed to assure representative analyses of the river. A fixed site design identified river sample points located in a pattern to detect influences of tributary inflows, current irregularities, and light and intensive recreational use on Colorado River water quality; surface water and bottom sediment samples were collected at fixed sites. A time series sample design complemented the fixed site design by assuring comprehensive sampling of the Colorado River surface waters through time; surface water samples were collected at 0800, 1200, and 1800 hours each day at the location of the research rafts at the specified period.

Tributaries were sampled by a fixed site design. Multiple sites were located at Hermit Creek, Elves Chasm, Deer Creek, and Havasu Creek to detect potential water quality associations with intensive recreational use. Surface water and bottom sediment samples were collected from selected tributaries.

C. RESEARCH FINDINGS

Data from 1978 and 1979 show that the Colorado River and tributaries have similar bacterial water quality profiles. Surface waters show predominantly low FC densities, indicating high quality waters for recreational activities, based on established federal and state water quality standards. Treatment of river and tributary surface water is necessary to assure drinking water quality standards.

The distribution of FC bacteria in the Colorado River is generally uniform along its length in Grand Canyon. There are no apparent associations between the Colorado River surface water quality and potential influences of tributary inflows or intensive recreation use river sites. Colorado River water quality data for 1978 and 1979 do not accurately reflect the effects of major watershed flushing from summer convection storms; a dry climate regime persisted in 1978 and 1979. Significant surface water quality impacts can be anticipated in conjunction with major storm water runoff events as watersheds are flushed and fecal matter is carried into the streams. Data from 1978 and 1979 suggest that storm water runoff can have critical impacts on Colorado River and tributary water quality, but additional research of this phenomenon is necessary to determine its significance.

Ratios of FC and FS densities indicate that the predominant source of fecal contamination in the river and tributaries is from nonhuman sources. Fecal contamination from nonhuman sources should not be discounted as unimportant as some enteric pathogens which can infect man also occur in a variety of wildlife and livestock species.

Bottom sediment FC densities in both the river and tributaries are generally significantly higher than in surface waters (see Figure 27 for an overall graphical illustration of surface water-bottom sediment water quality relationships). Log mean surface water FC densities in the river for 1978 were 2.1 FC/100 ml and for 1979, 2.4 FC/100 ml; tributary surface water log mean FC densities were 3.6 FC/100 ml and 8.0 FC/100 ml for 1978 and 1979, respectively. Log mean bottom sediment FC densities in the river were 110 FC/100 ml and 51 FC/100 ml in 1978 and 1979, respectively; tributary bottom sediment log mean FC densities were 422 FC/100 ml and 2188 FC/100 ml in 1978 and 1979, respectively. The extreme high FC density of 1165 FC/100 ml was recorded in the Colorado River surface water, but 75% of the samples taken showed less than 3 FC/100 ml. The extreme high FC density detected in a tributary was 4810 FC/ml, but more than 75% of the tributary samples had FC densities of 11 FC/100 ml or less. Bottom sediment densities in the river and tributaries reached 48,000 FC/100 ml on several occasions; 43% of the bottom sediment samples exceeded 500 FC/100 ml and 34% of the samples exceeded 1000 FC/100 ml.

Bottom sediment analyses modify considerably the water quality status represented by surface water analyses alone. Singificant densities of enteric organisms are present in the river and tributary environments, representing an important water quality hazard. Associated with resuspension of bottom sediments is the probability of surface water contamination by enteric organisms. Recreational activities, particularly water play in confined tributary pools, can bring river runners in direct contact with concentrated sediment suspensions in surface waters.

D. CONCLUSIONS

1) The microbiological quality of river and tributary surface waters, during periods of low turbidity, are generally acceptable for recreation activities, including full body contact. There is a high probability of surface water degradation if activities resuspend sediments, especially in tributary pools where intensive use and flow characteristics can temporarily concentrate sediment suspensions.

2) Research indicates that turbid storm water flows in the river or tributaries have a high potential for significant microbiological contamination. Additional water quality analyses are necessary to confirm this phenomenon.

3) When not carrying storm water runoff, tributary inflows in the summer season have not shown any detectable effects on Colorado River surface water microbiological quality.

4) Regardless of turbidity levels or collection location, surface waters of the Colorado River and tributaries require treatment to assure drinking water standards.

5) Enteric organisms are concentrated in the bottom sediments of the Colorado River and tributaries at levels which represent microbiological water quality hazards to river runners and other recreationists using the water resources of the Colorado River corridor. If disturbed, bottom sediment FC densities can degrade surface waters beyond microbiological contact standards; suspended sediments can impair the ability of water treatment techniques to assure microbiological drinking water standards.

6) Surface water analyses alone cannot be considered sufficient to determine the water quality status of recreational streams and lakes; bottom sediment analyses must complement surface water examinations to provide an accurate water quality perspective.

7) Based on 1978 data, the chemical water quality status of the Colorado River and tributaries, with few exceptions, reflects conditions which are in line with those expected of natural waters.

8) Bottom sediment water quality standards are needed for evaluation and management of natural recreation waters. Research effort should be extended to quantify the relationship between bottom sediment FC densities and recreation water quality hazards.

E. RECOMMENDATIONS

Based on the findings of this research, recommendations are offered in two categories: 1) water quality and recreation float trip use of the Colorado River corridor, and 2) water quality monitoring and research in the Colorado River corridor.

1. Water Quality and Recreation Float Trip Use of the Colorado River Corridor

Water quality hazards in the Colorado River and tributaries are primarily associated with a) bottom sediments, b) turbid storm water runoff, and c) drinking water.

a) Surface waters of the Colorado River and tributaries are generally acceptable as full body contact resources if no turbidity is visible; water play presents a paradox to this situation. Bottom sediments are inevitably resuspended by water play activities especially in confined, shallow tributary pools with sediment characteristics as occurring at Elves Chasm or parts of Havasu Creek. Associated with sediment resuspension is a high probability of microbiological degradation of water quality, perhaps exceeding full body contact standards. Accordingly, caution and good judgment should be exercised when engaging in water play. Ideally, river runners should choose tributary pools, as at Shinumo Creek (mile 108) or in parts of Havasu Creek (mile 157), with gravel or stone bottoms or with sufficient depth to avoid resuspension of bottom sediments during water play. Water play in pools can create critical water quality hazards and use of these areas may require restrictions; river runners should cease activities which dislodge the bottom sediments or exit water when turbidity becomes visible in the surface waters. Total submergence of the body is associated with the highest risk of ingestion of surface waters, and as a minimum precaution should be avoided if visible turbidity is present. Indiscriminate and simultaneous use of Elves Chasm by large groups of people will cause significant sediment disruption; intensive water play should therefore be restricted.

Water play activities generally will have less critical impacts on Colorado River surface water quality than in tributaries. The currents and volume of the river quickly disperse suspended sediment and cold water temperatures usually discourage most river runners from prolonged, concentrated water play. In some shallow, quiet flow areas, as at Redwall Cavern (mile 33), the action of people and/or boats could combine to create significant sediment suspensions and prudent river runners should avoid total submergence contact.

b) Storm water runoff combines the water quality hazards of bottom sediment resuspension from flood level flows and watershed flushing. Microbiological contamination of storm water runoff is probable and full body contact in storm affected tributaries or the river is not recommended.

c) In addition to following NPS treatment recommendations for all drinking water collected from the Colorado River corridor, there are several steps river runners should take to insure the quality of their drinking water. If flowing relatively clear, the main course of the Colorado River should be used as the primary source of drinking water; collect water away from the immediate shoreline contact with beaches and avoid sediment cloud suspension occurring from wading or upstream disturbances. The volume of water in the Colorado River acts to dilute the impacts of contamination which could occur; small tributary flow volumes do not provide this advantage.

Tributaries are secondary choices for drinking water sources and are not to be used unless the Colorado River is heavily sediment laden from Canyon storm water runoff, as when the Little Colorado River is in flood. Tributaries could be used as alternative sources provided they are flowing clear. Side creeks which should always be avoided as sources of drinking water include: Paria River, Little Colorado River, Bright Angel Creek, Garden Creek, Hermit Creek, Elves Chasm, Havasu Creek, and Diamond Creek. Caution should be exercised during water collection from a tributary so as to avoid disruption of bottom sediments. Water should not be collected following human water play activities at the site or upstream. Treatment is essential before consumption.

Frequently river runners have no choice but to use turbid, sediment laden water for drinking purposes; the Colorado River is the best selection in these events. An essential process in utilizing turbid water for drinking is settling of the sediment, preferably overnight, and decanting the supernatant water into a clean container before treatment to avoid the microbial contamination often associated with particulate matter and reduce the nullifying effect sediment can have on chlorine disinfectants. Settling can be accomplished best in a deep container, such as a bucket, by pouring settled water into a clean container slowly to avoid stirring the sediment on the bottom of the bucket.

National Park Service management has taken the necessary steps (i.e., sewage carryout and sanitary procedures) to minimize impacts from river runners on the water resources in the Colorado River corridor; at this juncture no other apparent actions could be taken to reduce the microbial concentrations found in these resources. The key to coping with the water quality hazards found in the river corridor is user awareness and understanding of the existing and potential hazards. National Park Service management should institute a water quality education program to be disseminated to all inner canyon users including commercial and noncommercial river runners, Lees Ferry fishermen, and Grand Canyon backpackers. Water quality education would be a valuable addition to the annual commercial boatman training sessions. Visitors to the Colorado River corridor should know how to recognize and handle water quality problems as they occur.

2. Water Quality Monitoring and Research in the Colorado River Corridor

Water quality monitoring and additional research in the Colorado River corridor is recommended. Water quality monitoring, including bottom sediment analyses during the river running season, will keep management aware of potential water quality hazard areas; particularly popular side creek attraction sites. Monitoring processes will also provide future opportunities for critical research on the water quality implications of turbid stream water runoff; these conditions were rare in 1978 and 1979 but potentially represent significant water quality hazards.

An extension of the Colorado River water quality research is recommended for the 14-mile stretch of the river between Glen Canyon Dam and Lees Ferry. Day use of this section of river by fishermen, boaters, and one-day raft trips have increased dramatically over the last few years, reaching an annual total of over 15,000 user days for 1979. Bottom sediment FC densities at Lees Ferry for 1979 show a considerable increase over 1978 levels, suggesting potential water quality hazards there and presumably upstream. Presently, the water quality status of this 14-mile stretch is limited; current use levels and the lack of sanitation policies suggest the potential for water quality impacts on river users as well as human impacts on the river. Research is needed to clarify this situation.

Concern for surface water-bottom sediment water quality relationships can also be extended to other water resources within Grand Canyon but away from the immediate river corridor. Bottom sediment examinations are advisable extensions of the National Park Service 208 Water Quality Project research of inner canyon streams utilized by backpackers.

SECTION II

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II. RESEARCH INTRODUCTION

Research in Grand Canyon conducted by the University of Arizona in 1978 and 1979 was designed to examine associations between river recreation activities and water quality. Baseline profiles of selected water parameters were 1) established for the Colorado River and the lower confluent reaches of 26 tributaries and 2) evaluated for potential impacts on river runners based on the pattern of their water use anc contact. Evaluations of potential impacts were facilitated by selection of sample sites representing varying types of recreation activities and use intensities. Research analyses concentrated on microbial water quality parameters; detection and quantification of fecal contamination in surface waters and bottom sediments, through an examination of densities of enteric indicator organisms, was an essential approach leading to the understanding of water quality hazards associated with river running recreation.

Previous water quality research in the Canyon examined only surface waters of the Colorado River and tributaries; researchers and management did not recognize nor examine critical associations between recreational activities, surface water quality, and bottom sediment microbial densities. Research elsewhere has established that bottom sediment can provide a microbial habitat where enteric organisms*, including pathogens, can persist and concentrate (Van Donsel and Geldreich, 1971; Hendricks, 1971; Motschall, 1976; Winslow, 1976; McKee, 1977; and Morse, 1979), representing a latent potential to dramatically degrade surface microbial water quality if resuspended by currents, wave action, or recreational activities (Hendricks, 1971; Geldreich, 1972; Motschall, 1976; Winslow, 1976; McKee, 1977; and Morse, 1979).

First concerns for potential water quality problems in the Colorado River corridor of Grand Canyon came in 1972 with a major outbreak of _Shigella sonnei_ (Merson et al., 1974), a gastrointestinal disease which can be transmitted in water contaminated by fecal matter. Early research (1975) evaluating microbiological water quality in the river corridor led the National Park Service (NPS) to conclude that generally unpolluted conditions existed (NPS, 1979a); management recommended that all drinking water from the river or side creeks be treated but had not identified any particular water quality hazards.

Section II includes A.) a briefing on the significance of the Colorado River corridor as a recreation resource, B.) research problem statement, C.) research purpose and objectives, D.) delineation of the scope of the study, and E.) a short description of pertinent inner Canyon physical and biotic characteristics.

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*Enteric organisms live in the intestines of warm blooded animals and are excreted in fecal matter; may be pathogenic or nonpathogenic.

A. COLORADO RIVER CORRIDOR AS A RECREATIONAL RESOURCE

Grand Canyon is a natural wonder known worldwide; its heritage and recreational resources have been preserved by inclusion in the National Park System since 1919. The special significance of the Colorado River corridor of the Grand Canyon has been more recently recognized. In the Proposed Colorado River Management Plan--Final Environmental Statement (NPS, 1979a), the National Park Service (NPS) summarizes the unique qualities of the river corridor (see also Figure 1):

> The Colorado River through Grand Canyon is one of eight stretches of recreation rivers on the Colorado-Green River system. It is one of more than 44 stretches of recreational rivers in the western United States.
>
> In Grand Canyon, the Colorado River has unique characteristics which set it apart from other rivers. It is the longest stretch of river for recreational use entirely within a national park. It is surrounded by more than 1 million acres of land with little human development. Some of the world's most difficult and exciting white water occurs here. The Colorado River's isolation in the mile deep gorge of Grand Canyon gives it wilderness qualities which enhance in addition to river running, off-river hiking, climbing, sightseeing, and solitude.

Popular use of the Grand Canyon for recreation float trips has been a recent phenomenon (Table 1). Following the completion of Glen Canyon Dam and creation of Lake Powell (1966), dramatic increases in river travel through the Canyon occurred; the NPS discusses the factors influencing this trend:

> Pre-dam flows were so high during spring runoff that river running was difficult. On some years, flow volume dropped so drastically that be September there was too little water for river running. The more consistent flows and clear water resulted in the Colorado River below Glen Canyon Dam becoming one of the most sought-after whitewater recreation rivers in the Western Hemisphere. Simultaneously other factors encouraged the growth in river running: emerging interest in wilderness experience, increased mobility and leisure time, expanding numbers of people with river-running expertise, and an increased amount and variety of, as well as improvement in equipment (Proposed Colorado River Management Plan--Final Environmental Statement, 1979).

Annual river float trip participation was, in 1973, restricted by management to 1972 user levels; restrictions stemmed from concern that increased use was having a negative impact on the resources and on the visitors' river experience. An NPS-sponsored research program was

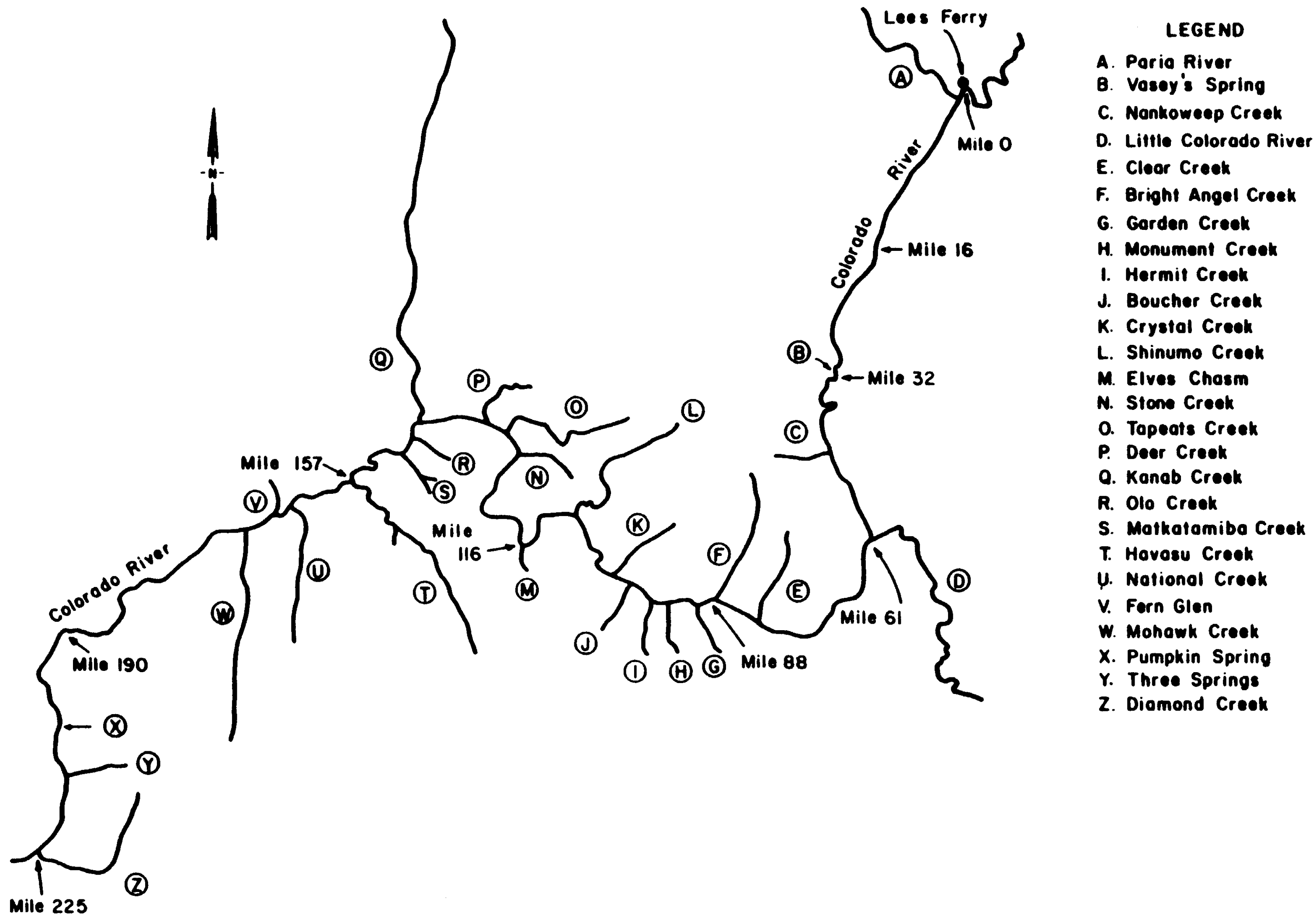

Figure 1. Colorado River and Tributaries through Grand Canyon.

Table 1. Travel on the Colorado River through the Grand Canyon from 1867 to the Present (NPS, 1979a).

Year	Number of People	Year	Number of People
1867	1	1959	120
1869-1940	73	1960	205
1941	4	1961	255
1942	8	1962	372
1943	0	1963-1964	44[1]
1944	0	1965	547
1945	0	1966	1,067
1946	0	1967	2,099
1947	4	1968	3,609
1948	6	1969	6,019
1949	12	1970	9,935
1950	7	1971	10,385
1951	29	1972	16,432
1952	19	1973	15,219[2]
1953	31	1974	14,253
1954	21	1975	14,305
1955	70	1976	13,912
1956	55	1977	11,830
1957	135	1978	14,356
1958	80	1979	13,228[3]

[1]Travel on the Colorado River in these years was curtailed by the completion of Glen Canyon Dam upstream and the resultant disruption of flow.

[2]The downturn in visitation was the result of the institution by management of a quota system. The numbers applying for the available private permits continued to rise annually.

[3]Estimate based on NPS data through September 1979 (NPS, 1979b).

conducted from 1973 through 1976 to assess these apparent impacts. The Proposed Colorado River Management Plan, scheduled for implementation in 1980, has been scaled in view of the research findings to minimize impacts to the Canyon environment and experience.

Commercial and noncommercial float trips occur through the narrow corridor of Grand Canyon. Commercial trips are sponsored by licensed concessioners providing guides and equipment for a fee; noncommercial trips are sponsored by private parties who organize their own outfit for purposes of the trip. Current (1972 use restrictions) allocations provide commercial river running permits with 92% of the available user days and private permits (noncommercial) with 8%; the Proposed River Management Plan calls for a 75% commercial and 25% noncommercial user allocation system.

Both motorized and row trips are permissible on the river. Most of the commercial trips are motorized; virtually all of the private trips are row. Under the Proposed River Management Plan, motorized trips will be phased out in favor of river travel exclusively by oar, total user days for the river will be increased, use will be dispersed throughout the year, commercial allocations will be reduced, and noncommercial allocations will be increased. Table 2 summarizes these changes.

River trips begin at Lees Ferry and end at Diamond Creek (mile 225*), Pierce Ferry, or Temple Bar. Pierce Ferry and Temple Bar are on Lake Mead which backwaters to river mile 240. An access road traverses the Hualapai Indian Reservation to meet the river at Diamond Creek.

Currently, commercial trips average 9 days and noncommercial trips average 15 days. Overnight camps may occur on any of about 400 possible beach sites in the 225-mile corridor, although less than 100 beaches receive 75% of the camping activity (Carothers et al., 1975).

River trips must be self-contained, carrying in all supplies, with the exception of water, and carrying out all waste, including human sewage. Human sewage carryout became a mandatory operating requirement in 1978 when the NPS determined, based on research (Phillips and Lynch, 1977), that the traditional practice** of beach burial of sewage was having a cumulative undesirable effect.

Off-river sites are important attractions to river travelers. Side creeks such as Little Colorado (mile 61), Shinimo (mile 108), Elves Chasm (mile 116), Tapeats Creek (mile 133), Deer Creek (mile 136), and Havasu Canyon (mile 157) receive frequent and at times concentrated use from river trips.

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*River miles are measured from Lees Ferry (mile 0) downstream.

**Before 1978.

Table 2. Current and New Use Limits (NPS, 1979a).

	1978 Limits		Proposed Management Plan	
	Summer	Winter	Summer	Winter
COMMERCIAL				
Minimum Trip Length (days)	6	6	8	8
Maximum Trip Length (days)	No Limit	No Limit	18	21
Average Trip Length (days)	9	9	12	12
Passengers per day (max)	150	150	50	50
Launches per day	No Limit	No Limit	2	1
Launches per week	No Limit	No Limit	14	up to 3
Passengers per group	40	40	25	25
Number of People	11,335	*	9,150	975
Number of Trips	491	*	366	39
Projected User Days	89,000	*	109,800	11,700
Maximum User Days	89,000	*	164,700	20,475
NONCOMMERCIAL				
Minimum Trip Length (days)	No Limit	No Limit	No Limit	No Limit
Maximum Trip Length (days)	No Limit	No Limit	18	21
Average Trip Length (days)	19	19	16	18
Launches per day	1	1	1	1
Launches per week	**	**	7	7
Participants per group	15	15	15	15
Number of People	395	***	2,745	585
Number of Trips	37	***	183	39
Projected User Days	7,600	***	43,920	10,530
Maximum User Days	7,600	***	49,410	12,285

* The previous number of people, trips, and user days for commercial river running was allocated annually with no distinction as to season. Therefore, winter use is included in the summer use figures.

** Launches per week was limited by the number of people that could launch each day, and the annual limit.

*** The previous annual noncommercial use allocation of 7,600 user days has worked out to about 40+ trips each year. No more than 1 noncommercial trip could launch each day. Theoretically, 7 trips could launch each week. This rarely occurred because of the overriding limit of about 40 trips each year, based on the annual user day limit.

The previous number of people, trips, and user days for noncommercial river trips was allocated annually with no distinction as to season of use. Some winter use is included in the 1978 summer use figures.

Access to the inner Canyon and the Colorado River corridor is not limited to river travel. Numerous trails permit hikers to explore the Canyon and reach the river. Hikers use the side creeks and river, as do river runners, for domestic water needs. Six trail systems receive the bulk of the hiker interest; use of these trails from April through September 1978 and 1979 is indicated in Table 3.

B. RESEARCH PROBLEM STATEMENT

Management agencies have only recently begun to question the quality of natural waters used for recreation. The remote and wild recreational white water rivers of the West are not exempt from negative impacts affecting their water quality status. During the summer of 1972, an outbreak of gastroenteritis* occurred among river runners on the Colorado River of Grand Canyon. The 1972 illnesses were attributed to shigellosis; the enteric pathogen *Shigella sonnei* was isolated by the Center for Disease Control, Atlanta (CDC) from some of the river runners (Merson et al., 1974). During the 1979 summer season, the events of 1972 repeated; *Shigella* was again isolated from persons encountering the illness while on the river. Potentially, the Colorado River or a tributary creek served as a source for the pathogens during the 1972 and 1979 outbreaks, though this has not been confirmed. River water was readily used for drinking and cooking purposes; frequently, without treatment. Propagation of the disease once established was probably from person to person (Merson et al., 1974).

Fecal contamination is the usual degrading element in recreational waters used for primary or secondary contact or for drinking water purposes. Enteric disease organisms pass from the body in feces and become a potential source of infection; water contaminated with the organisms can distribute diseases (Table 4).

Dramatic increases in float trip participation have occurred in Grand Canyon as well as on other western rivers. Considering 1975 participation levels** in Grand Canyon, Phillips and Lynch (1977) speculated that persons joining river trips will be carrying or be infected with enteric pathogens at the same rate of occurrence as the national population. The incidence of salmonellosis in humans in the United States is less than 1% (Hall and Hauser, 1966), and that of shigellosis is approximately 0.46% (Reller et al., 1970). Assuming 14,000 persons per year float the Colorado River, about 140 people could be expected

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*Gastroenteritis is one of several diseases of the stomach and intestines caused by one of a number of enteric pathogens (Table 4): associated symptoms include diarrhea which may be explosive, nausea, vomiting, headache, and weakness. Often temporarily debilitating, severe cases could lead to fatality.

**14,305 persons floated the Colorado River in 1975.

Table 3. Hiker Use of Major Trail Systems (NPS, 1979b).

Figures for April-September	1978	1979
Tanner Trail*	374	537
Hance Trail*	298	429
Boucher Trail*	293	339
Hermit - Tonto Trail**	5,225	5,675
Thunder River (Tapeats-Deer Creek) Area**	2,202	2,105
Bright Angel, Indian Gardens, Cottonwood**	24,963	23,630
Total Number of Hiker Nights	67,118	73,158***

* Number of hikers only, the number of nights each hiker spent in the area is unknown. 2.5 nights per hiker would be a reasonable estimate.

** Number of hiker nights, one person staying per night.

*** Figure is based on projected increase of 9% for 1979 over 1978.

Table 4. Enteric Diseases and Infections (modified* from Phillips and Lynch, 1977).

Organism	Disease or Infection
Bacterial infections	
Klebsiella pneumoniae	Highly fatal type of pneumonia or lesions which may occur in any part of the body.
Proteus spp.	Genito-urinary and gastro-intestinal tract diseases.
Salmonella (180 different serotypes reported in 1973)	
S. typhi	Typhoid fever may be transmitted by flies; incubation period, 10-14 days.
S. paratyphi (type A) S. schottmuelleri (type B) S. hinschfeldii (type C)	Paratyphoid fever - resembles typhoid, but less severe.
S. typhimurium S. newport S. enteritidis	Three most commonly isolated sero-types causing salmonellosis, an acute gastrointeritis with diarrhea. Symptoms occur within a few hours of infection.
Shigella dysenteriae	Most severe form of shigellosis or bacterial dysentery. Several other species of Shigella may cause the disease. The incubation period is 1-7 days (4 av.).
Virus diseases	
Poliovirus	Paralytic poliomyelitis, aseptic meningitis.
Coxsackie	
Group A	Herpangina, aseptic meningitis.
Group B	Pleurodynia, aseptic meningitis.
Infectious Hepatitis	Infectious hepatitis. The incuba-tion period is 15-50 days (25 av.).
ECHO	Aseptic meningitis, "summer" rash, diarrheal disease.
Adenovirus	Respiratory and eye infection.
Protozoan diseases	
Entamoeba histolytica	Amebiasis with symptoms ranging from abdominal discomfort to severe dysentary.

Table 4.--continued.

Organism	Disease or Infection
*Giardia lamblia	Parasitic disease of small intestine, symptoms range from abdominal discomfort to severe dysentary.

*Giardasis is a protozoan disease which is recently becoming more prevalent in the western United States (Jakubowski and Huff, 1979).

to carry or be infected by salmonellosis and approximately 60 people by shigellosis. Nationally both diseases show annual peaks of occurrence in the summer and autumn months (Geldreich, 1972) which coincide with the river running season.

The potential for disease introduction into the Canyon water resources by humans is increased by the potential impact of 250,000 to 300,000 day hikers per year in Grand Canyon, the approximately 75,000 hiker nights to be spent in the Canyon in 1979, the over 15,000 persons (predominantly fishermen) who will utilize the 14-mile stretch of the Colorado River between Glen Canyon Dam and Lees Ferry for recreation in 1979, the presence of the Havasupai Indian town of Supai and the thousands of hikers annually visiting there on Havasu Creek (an inner Canyon tributary of the Colorado).

Wildlife and livestock within the Grand Canyon and on tributary watersheds from outer Canyon areas cannot be discounted as potential sources of contamination to inner Canyon water resources. Salmonella spp. is found in 13% of clinically healthy farm cattle and in 3.7 to 15% of clinically healthy sheep in the United States (Rothenbacker, 1965). Wild and domestic animal populations including beaver, coyote, dogs and cattle have been identified as being reservoirs of Giardia spp. organisms (Davies and Hibler, 1979); these species are all indigenous to the Grand Canyon area.

1. Previous Water Quality Studies of the Colorado River Corridor

Based on available research data, water quality conditions in the Colorado River corridor have been assessed in the proposed river management plan (NPS, 1979a). "Unpolluted conditions" were concluded to exist with the noted exceptions that during periods of the year, during peak flows or at specific tributary sites, contaminants may exceed U.S. Public Health standards for human drinking water. The NPS recommended that all natural waters in Grand Canyon be treated before drinking; commercial river guides have been required to have treated water available for passenger use.

A review of the available water quality research data for Grand Canyon, presented in the proposed management plan, indicates that an adequate basis does not exist for a comprehensive assessment of the associations between float trip recreation and water quality conditions in the river corridor. While the general conclusions in the management plan may be reasonably accurate, they are not confirmed nor denied by research. The major shortcoming is the lack of comprehensive data on fecal contamination; a highly variable water quality parameter which can reveal potentially severe impacts on public health (Geldreich, 1966). Analyses of fecal contamination reported by NPS (1979a) in the river corridor were conducted in 1975. Basic 1975 research deficiencies included a limited sampling program and failure to recognize the critical relationship between overlying surface water quality and microbial concentrations in bottom sediments.

The Colorado River extends 225 miles through Grand Canyon, merging with more than 30 tributaries. Intensive use of the river corridor occurs during the summer river running season from May through September. A representative water quality research design should include intensive sampling of the river and tributaries throughout at least one river running season.

The 1975 research presented in the proposed management plan was based on a total of four sampling periods. Samples were collected during the months of June, August, November and March; only two of the periods, June and August, represent the intensive use period of the summer river running season. An average of only 10.25 river samples and 11 tributary samples were collected from the 225-mile river corridor each sample period.

2. Bottom Sediment Water Quality Considerations

Water quality surveys are usually restricted to observations of surface waters, a practice which overlooks the significance of sediments. Bottom sediments may serve as a concentrated and stable index of the microbial quality of the overlying water (Van Donsel and Geldreich, 1971), and as a potential reservoir of pathogens which can degrade the quality of the overlying water if dislodged (Geldreich, 1971; Motschall, 1976; Winslow, 1976; and McKee, 1977). Examining two recreational streams in southern Arizona, Motschall (1976), McKee (1977), and Brickler and Morse (1979) found dramatic increases (10^2- to 10^6-fold) in fecal coliform* densities in bottom sediments over surface water concentrations.

A number of investigators have examined the relationship of microbial organisms to the sediment environment. Hendricks and Morrison (1947) found that sediments loosely bind basal nutrients, providing an environment which facilitates the survival of various enteric bacteria. Two interactive processes appear responsible for increased recoveries of bacteria from sediments; benthic environments are areas where 1) bacteria are received by sedimentation and absorbed onto particles and 2) where the survival and/or growth of bacteria is promoted (McKee, 1977). Hendricks (1971) described benthic mud as a stable environment where pathogenic and nonpathogenic organisms can concentrate and persist. Effectively, bottom sediments serve as a reservoir of bacteria giving a false pretense of quality when surface waters alone are sampled and found acceptable.

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*Fecal coliforms are a group of enteric bacteria native to the gut of warm-blooded animals and which are excreted in feces. Rarely pathogenic, fecal coliform densities are measured as indicators of fecal contamination. Arizona state water quality standards specify allowable limits of fecal coliform occurrence; the bacteria are especially prominent in the human digestive system.

Many avenues of intermixing potential pathogens in bottom sediments into overlying surface waters are possible and include 1) disruption of bottom sediments by bathers or waders, 2) agitation of the bottom by actions of power boats, 3) the action of currents in streams, 3) stream bottom and bank scouring by storm runoff flows, and 5) flushing of watersheds during storms.

Bottom sediment water quality has not previously been examined in the Grand Canyon.

3. Management Actions Taken Regarding Water Quality in Grand Canyon

The NPS has taken steps to minimize possible impacts on Grand Canyon water resources by river runners. In 1978, the practice of beach burial of human waste in Grand Canyon was terminated by requiring all river trips to carry out their sewage; Phillips and Lynch (1977) estimated that 20 tons of solid human waste were being buried in Colorado River beaches each river running season. The NPS has taken the action necessary to reduce contamination of water resources in the Colorado River corridor. Potential water quality associated problems have not been eliminated as other probable sources of contamination (e.g., tributary drainages, hikers, wildlife and domestic stock) are not as easily neutralized. The 1979 problem with shigellosis among river runners has occurred since implementation of sewage carry-out requirements.

Accordingly, management must take steps to minimize potential water quality impacts on river runners and other inner Canyon visitors. Comprehensive knowledge of Colorado River corridor water quality will allow the reduction of public health hazards through actions such as water use regulations and water quality education.

In April of 1979, the NPS initiated a 208 water quality program which will monitor for one year 20 creek and spring sites frequented by hikers in Grand Canyon. Management has not implemented a similar program for Colorado River corridor water resources utilized by river runners.

C. RESEARCH PURPOSE STATEMENT

The purpose of this study is to develop a baseline profile of the water quality status of the Colorado River and the confluent reaches of its tributaries within Grand Canyon. Emphasis is placed on microbial water quality as it is associated with recreational float trip use of the Colorado River corridor. Results of the research will serve as a reference for NPS management policies for Grand Canyon and as a basis for future research of Grand Canyon and other western white water rivers.

D. RESEARCH OBJECTIVES

Research objectives:

1. Determine baseline water quality in four critical areas of the river corridor.

   a. The Colorado main course which serves as a source of drinking water for river float trips.

   b. Confluence reaches of the major Colorado River tributaries where warm water temperatures encourage river runners to engage in primary contact activities such as bathing and swimming.

   c. Beach-river interface where camping activities make primary and secondary contacts with the river.

   d. Beach-shoreline bottom sediments which can act as a reservoir of fecal contamination. Sediments are used for dish scouring and are intermixed into the waters by river activities.

2. Determine associations between float trip use and water quality in reflecting degrees of light and intensive recreation use patterns.

3. Determine the relationship between bottom sediments and bacterial concentrations to evaluate the potential health hazard of the use of sediments for activities such as dish scouring.

4. Determine the effect of tributary confluences on water quality in the Colorado River.

5. Develop management alternatives and recommendations, based on quality parameters, regarding recreational use of white water rivers for float trips.

E. SCOPE OF THE RESEARCH

Water quality analysis of the Colorado River corridor occurred during the 1978 and 1979 river running seasons. Travel through the Canyon was via research raft in a series of six float trips in 1978 and two float trips in 1979 (Table 5).

Table 5. Water Quality Research Float Trips.

1978 Dates	Days	1979 Dates	Days
17 April - 29 April	13	2 July - 12 July	11
21 May - 3 June	14	30 July - 9 August	11
3 July - 17 July	15		
23 July - 5 August	14		
13 August - 26 August	14		
3 September - 14 September	12		
Total Days	82	Total Days	22

Water quality samples were collected from the Colorado River along the 225-mile stretch from Lees Ferry to Diamond Creek, the launch and take-out points of the research trips. The confluent reaches (within approximately 200 meters of the Colorado River) of 26 side creeks in the river corridor were sampled in 1978; 9 tributaries were sampled in 1979. Additional samples were collected from upstream locations on some side creeks, bringing the tributary sample site total to 33 in 1978 and to 13 in 1979. Table 6 lists the side creeks sampled.

Selected microbial, physical, and chemical parameters were measured to determine baseline water quality status in the Colorado River corridor of Grand Canyon. Samples were collected from the surface waters and bottom sediments of the Colorado River and tributaries. Stir samples, collected from a sediment cloud suspended in the surface waters by agitation, were also obtained. Table 7 identifies the water quality parameters sampled in Grand Canyon.

Table 6. Tributary Water Quality Sample Sites.

1978	1979
Paria River	Little Colorado River
Vasey's Paradise Spring	Bright Angel Creek
Nankoweep Creek	Hermit Creek (4 sites)
Little Colorado River	Shinumo Creek
Clear Creek	Elves Chasm (Royal Arch Creek)
Bright Angel Creek	Deer Creek
Garden Creek	Kanab Creek
Monument Creek	Matkatamiba
Hermit Creek (4 sites)	Havasu Creek (2 sites)
Boucher Creek	
Crystal Creek	
Shinumo Creek	
Elves Chasm (Royal Arch Creek) (2 sites)	
Stone Creek	
Tapeats Creek	
Deer Creek (2 sites)	
Kanab Creek	
Olo Creek	
Matkatamiba	
Havasu Creek (3 sites)	
National Creek	
Fern Glen Creek	
Mohawk Creek	
Pumpkin Bown Spring	
Three Springs	
Diamond Creek	

Table 7. Grand Canyon Water Quality Parameters.

Parameter Measured	Year Measured	Type of Sample Measured		
		Surface Waters	Bottom Sediments	Stir Samples
Microbial densities	1978 & 1979	X	X	X (1979 only)
Fecal coliform bacteria	1978 & 1979	X	X	X (1979 only)
Fecal Streptococcus bacteria	1978	X		
Chemical concentrations				
Alkalinity	1978			
Phenothalene		X		
Total		X		
Hardness	1978			
Calcium		X		
Total		X		
Phosphate	1978			
Orthophosphate		X		
Total		X		
Nitrate	1978	X		
Chloride	1978	X		
Total dissoved solids	1978 & 1979	X		
pH	1978	X		
Physical				
Turbidity	1978 & 1979	X		X (1979 only)
Water temperature	1978 & 1979	X		
Air temperature	1978 & 1979	X		

F. DESCRIPTION OF THE STUDY AREA

Watershed characteristics, Glen Canyon Dam, river and tributary flow characteristics, climate, vegetation, and wildlife and domestic stock are examined as they have relevancy to water quality research in the Colorado River corridor.

1. Colorado River Corridor and Watershed Limits

The Colorado River corridor, the floor of Grand Canyon, is a narrow, linear environment stretching 256 miles from Glen Canyon Dam to the backwaters of Lake Mead, 240 river miles* downstream from Lees Ferry (see Figure 1). Cut within the relatively flat Colorado Plateau, the river corridor is isolated by the spectacular relief of Grand Canyon, a gorge 227 miles long and in places over a mile deep. The width of the Canyon floor is restricted, often confined by sheer walls to the river channel proper. A corridor width of about one mile occurs between the Canyon walls in the Tanner-Unkar region (miles 66-72). Usually the Canyon area negotiable by walking is limited to a few hundred feet or less from the river. Travel through the river corridor is possible only by boat. Short segments of the river course are accessible to hikers on trails descending from the rims through side canyons.

In the scope of this study, the Colorado River corridor refers to that central gorge of the Grand Canyon through which the Colorado River flows and to those accessible, adjacent areas visited frequently by river trips. Tributary side canyons form off-river extensions of the corridor where river parties hike to visit attraction sites.

Colorado River water enters the Grand Canyon from Lake Powell through Glen Canyon Dam. Flow through the dam from the 60,000 surface-acre lake is in response to hydroelectric demands and downstream irrigation needs. Water released from Lake Powell is traditionally considered to be of high recreational quality with low bacterial densities.

Watershed influences on water quality supersede the limits of the river corridor. Tributaries to the Colorado River potentially can have multiple impacts on river water quality corresponding to watershed characteristics and land use. Factors such as soil erosiveness, the presence of livestock or recreational use determine the quality of run-off from the watersheds which influences the quality of the Colorado River. Tributary influences are potentially pronounced during the summer season when monsoon rains can have a flushing effect on watersheds. Graphic illustration of this phenomenon is the fouling of the normally clear-running post-dam Colorado River with sediment from side creeks. Several tributaries including the Paria River, Little Colorado

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*River miles designate distances downstream from Lees Ferry.

River and Kanab Creek can foul the Colorado River with sediment for days or weeks.

Associated with watershed flushing are microbial contaminants less obvious than the brick red sediment the Colorado River receives. Geldreich (1972), Utter (1975), Motschall (1976), and Patterson (1977) found increased fecal coliform densities in surface waters following storm runoff events. Fecal contamination of tributary watersheds by livestock, wildlife, communities, or recreationists miles from the Colorado River can be transported into Grand Canyon.

With the exception of some tributary creeks, the watersheds associated with Colorado River corridor water quality are found within the rims of Grand Canyon. Notable exceptions draining areas above the rims include Paria River (drainage area 1410 mi^2), House Rock Wash, North Canyon Wash, Tanner Wash, Little Colorado River (drainage area 26,500 mi^2), Kanab Creek (drainage area > 1100 mi^2), Havasu Creek, Whitmore Wash, Parashant Wash, and Peach Springs-Diamond Creek.

2. Effects of Glen Canyon Dam

Since its completion on March 13, 1963, Glen Canyon Dam has significantly altered the temperature, sediment, and flow characteristics of the Colorado River through Grand Canyon.

a. Temperature Effects

Mainstream flow in the Colorado River released through Glen Canyon Dam is from the hypolimnion of Lake Powell; resulting annual water temperatures vary only 6°F from 42°F (5.6°C) to 48°F (8.9°C) at Lees Ferry approximately 14 miles downstream from the dam. At Diamond Creek (mile 225) summer temperatures of 62°F (17°C) may be reached in the river. Pre-dam temperatures varied more dramatically--winter lows in the 30's (°F) and summer highs in the 80's (°F).

Native fish such as the Colorado River squawfish (*Ptychocheilius lucius*) and the humpback chub (*Gila* spp.) which depend on seasonal temperatures for successful breeding are now limited to side creeks for reproduction and may face extinction. Cold, stabilized water temperatures are suitable for several species of trout which have been introduced and established in the Colorado.

Post-dam water temperatures may have influences on water quality and associated float trip recreation. Cold, stabilized temperatures slow natural die-off rates of enteric organisms introduced to the river by lowering the metabolic rates of the enteric organisms and the microbes that would prey upon them. Slowed mortality may be a significant factor facilitating the accumulation of enteric organisms in bottom sediments where nutrients are available for subsistence.

The establishment of a trout fishery between Lees Ferry and Glen Canyon Dam is attracting increasing numbers of fishermen (8000+ for 1979, up approximately 400 from 1978 (NPS, 1979b)). One-day raft trips and other visits to this 16-mile segment of the river bring the 1979 use total to approximately 15,000, a use itensity equivalent to that on the 225 miles of the Colorado River traveled by float trips. Associated with the use of the Lees Ferry to Glen Canyon Dam segment is an undetermined impact on the water quality there and downstream.

b. Sediment Effects

Glen Canyon Dam and Lake Powell have blocked significant sediment input to Grand Canyon from upstream Colorado River. Turbidity in the Colorado River below Lees Ferry is predominantly a function of tributary runoff into the Canyon. The pre-dam Colorado flow was sediment-laden; an average silt load per day passing Phantom Ranch was 500,000 tons (NPS, 1979a). Presently, in the post-dam era, the load is about 80,000 tons. Suspended sediment concentrations at Lees Ferry now range between 2 and 124 mg/l. At Phantom Ranch (mile 88), downstream from major tributaries including the Paria and Little Colorado Rivers, suspended sediment concentrations range from 6 to 47,000 mg/l (NPS, 1979a).

Pre-dam beaches have been altered by post-dam flows. Without the sediment inputs from the upper Colorado Basin, beach deposits have been stripped of significant silt content and are well sorted and predominantly sand. Notable beach silt contents are found only along wide quiet stretches of the river. Beach deposits with reduced silt contents may be less favorable microorganism habitats, as removal of fine particles reduces the internal surface area of the sediment available as a substrate to microbes.

c. Flow Effects

Pre-dam flows in the Colorado River were characterized by spring floods (up to 200,000 cfs at Lees Ferry (NPS, 1979a)), decreasing summer and fall flows (down to 700 cfs at Lees Ferry) and increasing late winter flows. Droughts or floods created extreme fluctuations in annual runoff volumes (4.4 million acre-feet to 18.0 million acre-feet (USGS, 1979)). Glen Canyon Dam and the storage capacity of Lake Powell have stabilized the flow of the Colorado River. Since 1969, discharges at Lees Ferry have varied between 1000 cfs and 32,000 cfs (NPS, 1979a) and runoff volumes have ranged between 7.8 million acre-feet and 10.8 million acre-feet (USGS, 1979).

Dam releases are in response to hydroelectric power demands and downstream irrigation needs. Seasonal peak flows have been shifted, in general, from the spring to the summer season. Power demands and irrigation needs in the arid Southwest and California are greatest in the hot summer period. Releases during the fall, winter, and early spring are usually conservative.

Power demands fluctuate hourly in the summer period as the need for air conditioning peaks late in the afternoon and early evening and declines through the night hours. As a result, a tidal type of effect occurs in Grand Canyon responding to variable hydroelectric releases. Water levels at Lees Ferry begin to rise in the late morning hours and peak in the evening. Water levels in narrow sections of the river channel can fluctuate 8 feet or more, and can change quickly, rising and falling as much as several feet in less than an hour.

Weekend power needs usually decline from workday levels and correspondingly so do river water levels.

Downstream flow in the Colorado River averages 4.5 miles per hour. Peak flows reach Lees Ferry (16 miles downstream from the dam) about 10 p.m. in the summer and at about 5 p.m. the next day at Phantom Ranch (104 miles from the dam).

A result of flow regulation on the Colorado River has been an extension of the river running season; pre-dam summer flows were often too minimal to allow river trips. Associated with the extended flow and river running season has been the increasing popularity of river trips and the intensive use of the river corridor; potential water quality problems have developed correspondingly.

Diurnal tidal flows of the post-dam Colorado River create specific types of water quality phenomenon. The rising waters of a downstream traveling peak scour the river bottom and beaches, picking up sediment. Turbidities can be increased from near zero levels during low flows to 100 FTU or more during high flows. Associated with the increasing turbidity is the potential for microbial contamination from resuspended bottom sediments. Turbidity increases are especially pronounced following minimum weekend flows as the rising front of Monday's peak inundates the beaches roughened by river runners over the weekend.

3. Seasonal Tributary Flows

Grand Canyon tributaries to the Colorado River reach a snow melt runoff peak in the spring, decline in the early summer months, may flood sporadically during the July-August-September monsoon rain season, and decline again through the fall and early winter seasons. Tributary flows do not add appreciably to the volume of flow of the Colorado River

4. Colorado River Corridor Climate and Vegetation

Riparian vegetation dominated by the post-dam invasion of salt-cedar (Tamarix spp.) borders the Colorado River flood zone, bisecting the desert community which extends to the Canyon walls (Figure 2). The floor of Grand Canyon is a desert climate, annual precipitation totaling about 8.3 inches and daytime summer temperatures reaching well over 100°F (37.8°C). Precipitation in the southwest falls predominantly in two seasons; a winter season (December through March) characterized by frontal storms and a summer monsoon season (July through September) with occasionally torrential convection storms. Summer convection storms can have an important impact on Grand Canyon water quality due to the flushing effects on tributary watersheds to the Colorado River corridor.

Mean monthly precipitation and temperatures for the inner canyon and four rim locations are shown in Table 8.

5. Wildlife and Livestock

With the exception of pack mules plying the trails between Phantom Ranch* and the south rim on a daily basis, the Grand Canyon is free of domestic animals. Wildlife is abundant with 248 recorded species of birds, 22 species of terrestrial animals, 18 species of bats, reptiles and amphibians occurring in the riparian zone of the Colorado River. Most notable in terms of visitor attraction are beaver, mule deer, bighorn sheep, and feral burros.

Tributary watersheds extending beyond the rims of the Canyon (see Section II.F.1) drain national forest, private, and Indian lands which are grazed by domestic stock.

*Phantom Ranch is a Park Service campground and a licensed concessioner lodge.

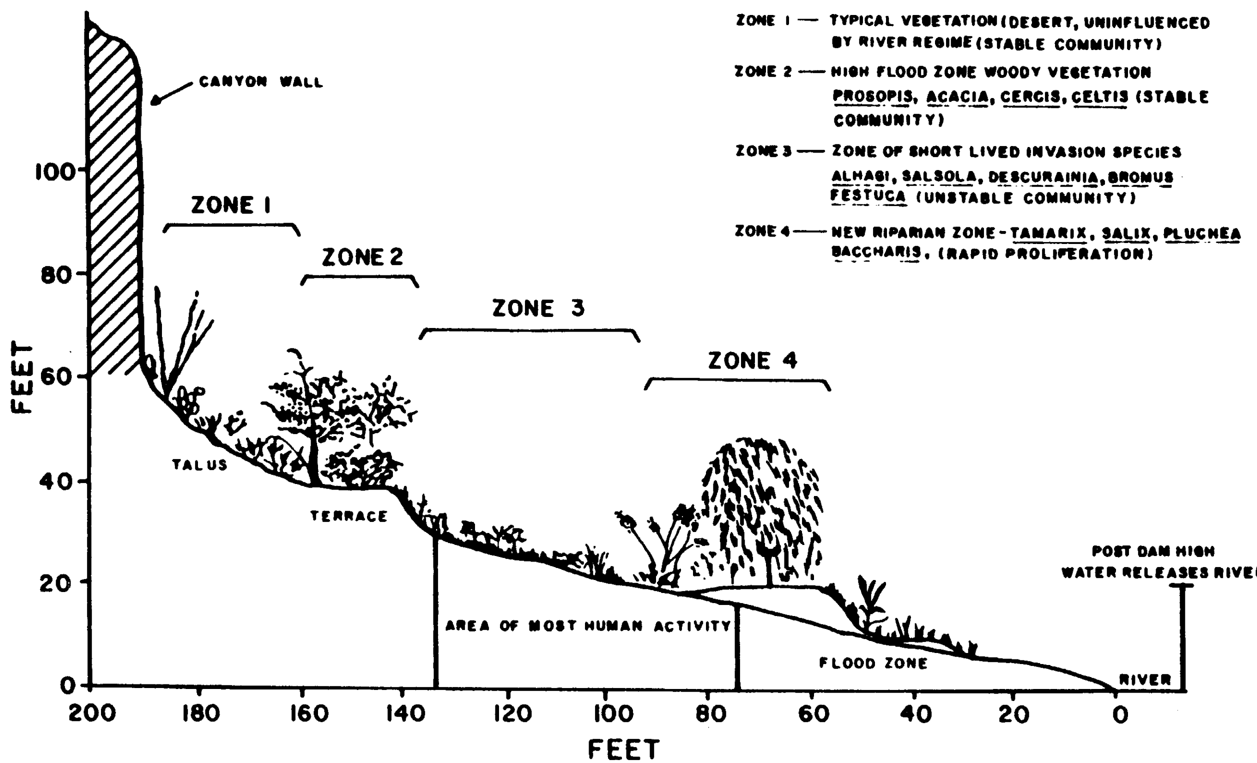


Figure 22. Post-Dam Riparian Vegetation.

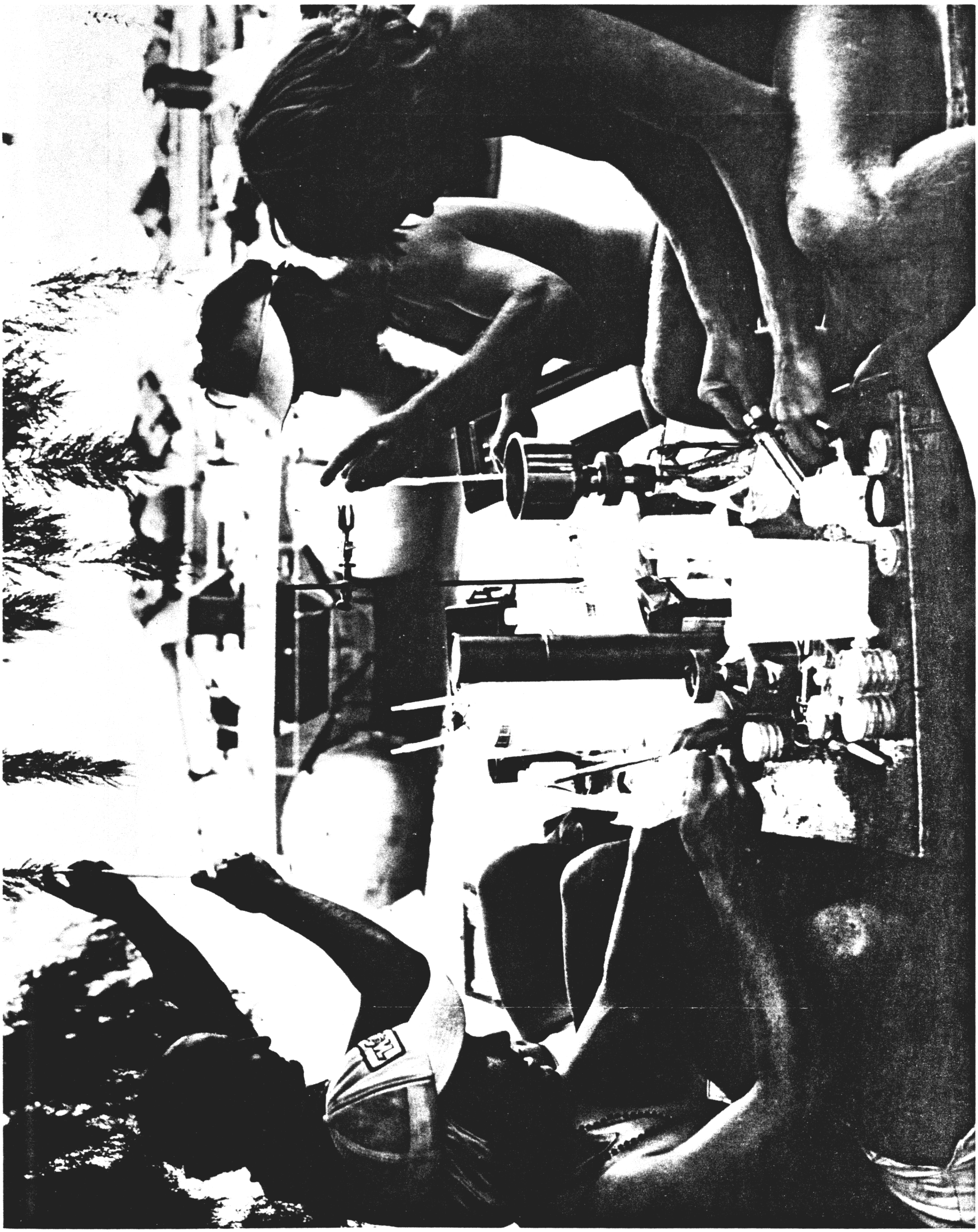
(From Carothers et al., 1976, in NPS, 1979a).

Table 8. Mean Precipitation and Temperature, Grand Canyon National Park (NPS, 1979a).

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN MAXIMUM TEMPERATURES (°F)												
Inner Canyon	56	62	71	82	92	101	106	103	97	84	68	57
Tuweep	49	50	61	68	79	89	95	92	85	74	61	49
Desert View	40	43	49	57	69	79	84	81	73	61	49	39
South Rim	41	45	51	60	70	81	84	82	76	65	52	43
North Rim	37	39	44	52	62	73	77	75	69	58	45	40
MEAN MONTHLY TEMPERATURES (°F)												
Inner Canyon	46	52	59	69	77	86	92	89	83	72	57	47
Tuweep	38	40	47	54	64	73	80	78	71	60	48	39
Desert View	30	33	38	44	56	65	71	69	61	50	39	30
South Rim	30	33	38	46	54	64	69	67	61	50	39	31
North Rim	26	28	34	40	48	56	62	60	54	45	35	30
MEAN MINIMUM TEMPERATURES (°F)												
Inner Canyon	36	42	48	56	63	72	78	75	69	58	46	37
Tuweep	26	30	34	40	49	58	65	63	56	46	35	29
Desert View	21	23	27	31	42	51	59	56	59	39	30	21
South Rim	18	21	25	32	39	47	54	53	47	36	27	20
North Rim	15	18	24	28	34	40	46	45	39	31	24	20
MEAN PRECIPITATION (Inches)												
Inner Canyon	.72	.73	.79	.48	.31	.28	.79	1.31	.88	.69	.51	.82
Tuweep	1.10	.90	1.25	.73	.40	.40	1.28	1.97	.79	.80	.77	1.31
Desert View	1.00	.94	1.52	.75	.50	.32	1.29	1.34	.99	1.39	.80	1.72
South Rim	1.32	1.53	1.37	.92	.65	.46	1.87	2.28	1.50	1.21	.95	1.61
North Rim	3.28	3.17	3.12	1.67	.97	.76	1.86	2.53	1.81	1.50	1.44	2.62
ANNUAL TOTALS - PRECIPITATION (Inches)												
Inner Canyon	8.31											
Tuweep	11.70											
Desert View	12.56											
South Rim	26.62											
North Rim	24.73											

SECTION III

RESEARCH METHODS



III. RESEARCH METHODS

Water quality analysis of the Colorado River corridor occurred during the 1978 and 1979 river running seasons. Examination of the extensive river corridor necessitated analyses in the field. Travel through Grand Canyon was via research rafts in a series of six float trips, April through September, in 1978, and two float trips, July and August, in 1979; 82 field days in 1978 and 22 field days in 1979.

A total of 497 water quality samples were collected over two years from the Colorado River along the 225-mile stretch from Lees Ferry to Diamond Creek, the launch and take-out points of the research trips. The confluent reaches (within approximately 200 yards of the Colorado River) of 26 side creeks in the river corridor were also sampled in 1978; nine tributaries were sampled in 1979. Additional samples collected from upstream locations on some side creeks brought the tributary sample site total to 33 in 1978 and to 13 in 1979 for a total of 215 individual tributary samples.

Selected microbiological, physical, and chemical parameters were measured to determine baseline water quality status in the Colorado River corridor of Grand Canyon. Research emphasis was on microbial water quality; physical and chemical parameters were measured to facilitate evaluation of the microbial profiles.

Section III addresses the specific methodologies and techniques used to accomplish the Grand Canyon research. This section is in four parts: A) water quality parameters; B) research logistics; C) research approach; and D) field analysis procedures.

A. WATER QUALITY PARAMETERS

Water quality analyses in the Colorado River corridor were directed towards providing an understanding of associations between recreational river running and water quality hazards. Accordingly, the research program was devised to closely examine fecal contamination of river corridor water resources and assess related potential impacts of recreational water use on river runners. Examination of selected water quality parameters provided data for the preceding evaluations. Microbiological parameters were the primary focus of the research; densities of fecal coliform (FC) and fecal streptococcus (FS) bacteria were measured as indicators of fecal contamination of water resources (Table 9). Chemical and physical water quality parameters were measured to complement assessment of microbial situations with baseline physical-chemical information (Table 9). Chemical and physical parameters examined are widely recognized and do not require special explanation; microbial parameters are not as commonly known, as considered by this research, and have been further clarified:

Table 9. Grand Canyon Water Quality Analysis Methodologies.

Parameter Measured	Sample Storage	Methodology	Reference
Microbial densities			
Fecal coliform bacteria in surface waters	Ice - maximum 6 hrs	Membrane filter/M-FC media/elevated temperature (44.5 ± 0.2°C)	Standard Methods, 1975
Fecal coliform bacteria in bottom sediments	Ice - up to 10 days	1978. Stored in Grand Canyon on ice/processed in Flagstaff/Multiple tube fermentation (MPN) 1. Presumptive test: lauryl tryptose broth for 24 to 48 hrs @ 35 ± 0.5°C 2. Confirmed test: EC broth for 24 hrs @ 44.5 ± 0.2°C	Standard Methods, 1975 Motschall, 1976 Appendix A
	Ice - maximum 2 days	1979. Processed in Grand Canyon/Multiple tube fermentation (MPN) 1. Presumptive test: lauryl tryptose broth for 24 to 48 hrs @ 35 ± 0.5°C 2. Confirmed test: membrane filters/M-FC media/ 24 hrs @ 44.5 ± 0.2°C	
Fecal coliform bacteria in stir samples	Ice - maximum 12 hrs	Processed in Grand Canyon as were 1979 bottom sediments	
Fecal streptococcus bacteria in surface water	Ice - maximum 6 hrs	Membrane filter/KF agar/48 hrs @ 35 ± 0.5°C	Standard Methods, 1975
Chemical concentrations			
Alkalinity Phenolphthalein ($CaCO_3$) Total ($CaCO_3$)	Ice - maximum 12 hrs	Titration - Hach field kit	Hach, 1973
Hardness Calcium ($CaCO_3$) Total ($CaCO_3$)	Ice - maximum 12 hrs	EDTA method - Hach field kit	Hach, 1973
Phosphate Orthophosphate (PO_4) Total (PO_4)	Ice - maximum 12 hrs	Stanna Ver* (stannous chloride) method - Hatch field kit	Hach, 1973
Nitrate (NO_3)	Ice - maximum 12 hrs	Reduction method - Hach field kit	Hach, 1973
Chloride (Cl^-)	Ice - maximum 12 hrs	Mecuric nitrate method - Hach field kit	Hach, 1973
pH	Immediate analysis	pH meter	
Physical			
Total dissolved solids (mg/l)	Ice - maximum 12 hrs	Conductivity method - Myron L DS meter	
Turbidity (FTU)	Ice - maximum 12 hrs	Colorometric - Hach field kit	Hach, 1973
Water temperature (°C)	Immediate analysis	Mercury thermometer	
Air temperature (°C)	Immediate analysis	Mercury thermometer	

*Stanna Ver is a Hach Chemical Company trademark.

1. Surface waters refers to the top layer of water, about 6" deep, of the Colorado River or side streams; the layer most frequently contacted by recreational use. In midchannel and some steep shoreline areas, bottom material was a considerable depth below surface waters; in shallow river shoreline and most tributary sites, surface waters were in a position directly overlying bottom materials. Fecal coliform and fecal steptococcus densities were determined in surface waters.

2. Bottom sediments were the unconsolidated materials, usually sand, in direct contact with the overlying water to a depth of approximately 2 inches; these materials had the greatest bacterial densities and were easily resuspended in the surface waters. River sediments were sampled only at shoreline sites; in shallow tributaries, midchannel and shoreline sediments were collected. Only FC densities were measured in bottom sediments.

3. Stir samples measured FC densities in a sediment cloud suspended in the surface waters by deliberate bottom agitation. The procedure demonstrated the potential for surface water microbial contamination by suspended bottom sediments.

B. RESEARCH LOGISTICS

Problems of access to the Colorado River corridor mandated the use of research rafts floating 225 miles through the Grand Canyon, from Lees Ferry to Diamond Creek, as a field base for intensive water quality analyses. Overland trails were not suitable passages into the river corridor in view of their ruggedness, distances, and scarcity; helicopters were restrictively expensive for extensive sampling programs. Research methods and equipment compatible with the rafting mode of travel on the Colorado River were adopted. Basic research river running logistics paralleled that of commercial and private oar-powered float trips. Discussion of research logistics and effects of river rafting on research design and methods follows.

1. Research Timetable

Having selected rafting as a means of travel in Grand Canyon, a float trip timetable was developed. The research period was timed to correspond with the popular river running season, April through September. Two research float trip scheduling options were considered: 1) trips 12 to 15 days in length, or 2) trips lasting 18 to 25 days. Short trips, option 1, would require daily progress through the 225-mile river corridor; sufficient time would exist for water quality analyses of tributary and river sites. Long trips, option 2, would move more slowly through the Canyon, allowing opportunity for repetitive sampling of selected sites over several days.

Option 1 was selected as it permitted a higher frequency (6 vs. 4) of sample periods during the 1978 research season (Table 5, Section II.E). Multiple trips also provided more opportunities for equipment resupply, repair and modification as research knowledge and needs expanded through the 1978 season.

2. River Running Equipment

Research trips were launched from Lees Ferry; take-outs were at Diamond Creek (mile 225) via the Peach Springs road. A truck shuttle to Flagstaff, Arizona carried equipment and personnel to and from the launch and take-out points (Figure 3).

Two "snout"-style oar-powered rafts were constructed for purposes of the research; boats of this type are of catamaran design with an inflatable pontoon 22 feet long by 3 feet diameter strapped either side of an aluminum frame 14 feet long, 7 feet wide, and 21 inches deep (Figure 4). An ice chest capable of holding 210 lbs was designed and constructed to fit within each frame. Ice was needed to preserve samples and media.

3. Special Logistical Procedures for Bottom Sediment Analyses, 1978

Bottom sediment analyses in 1978 required a conventional laboratory MPN methodology, as outlined in Van Donsel and Geldreich (1971), Motschall (1976), and McKee (1977), which was not suitable for field work in Grand Canyon. Accordingly, a laboratory-tested technique was developed to permit preservation of bottom sediment samples on ice in the Canyon until analysis in a state certified Flagstaff laboratory was possible (Appendix A). Bottom sediment samples collected in the Colorado River corridor were preserved on ice for periods up to 10 days until analysis in Flagstaff. Samples collected upstream of Phantom Ranch (mile 88) were transferred to a portable ice chest, lifted out of the Canyon by NPS helicopter, and driven to Flagstaff (Figure 3). Bottom sediment samples collected dowsntream of Phantom Ranch were stored in the raft ice chests and driven to Flagstaff at the conclusion of the float trip (Figure 3). Duplicate bottom sediment samples were collected at each site as a precaution against loss in storage or transport.

C. RESEARCH APPROACH

Research design for the Colorado River corridor incorporated two closely associated sampling programs: 1) the Colorado River sample design and 2) the tributary sample design. Both of these programs were developed to determine baseline water quality from the perspective of recreation management; each addressed the appropriate stated objectives

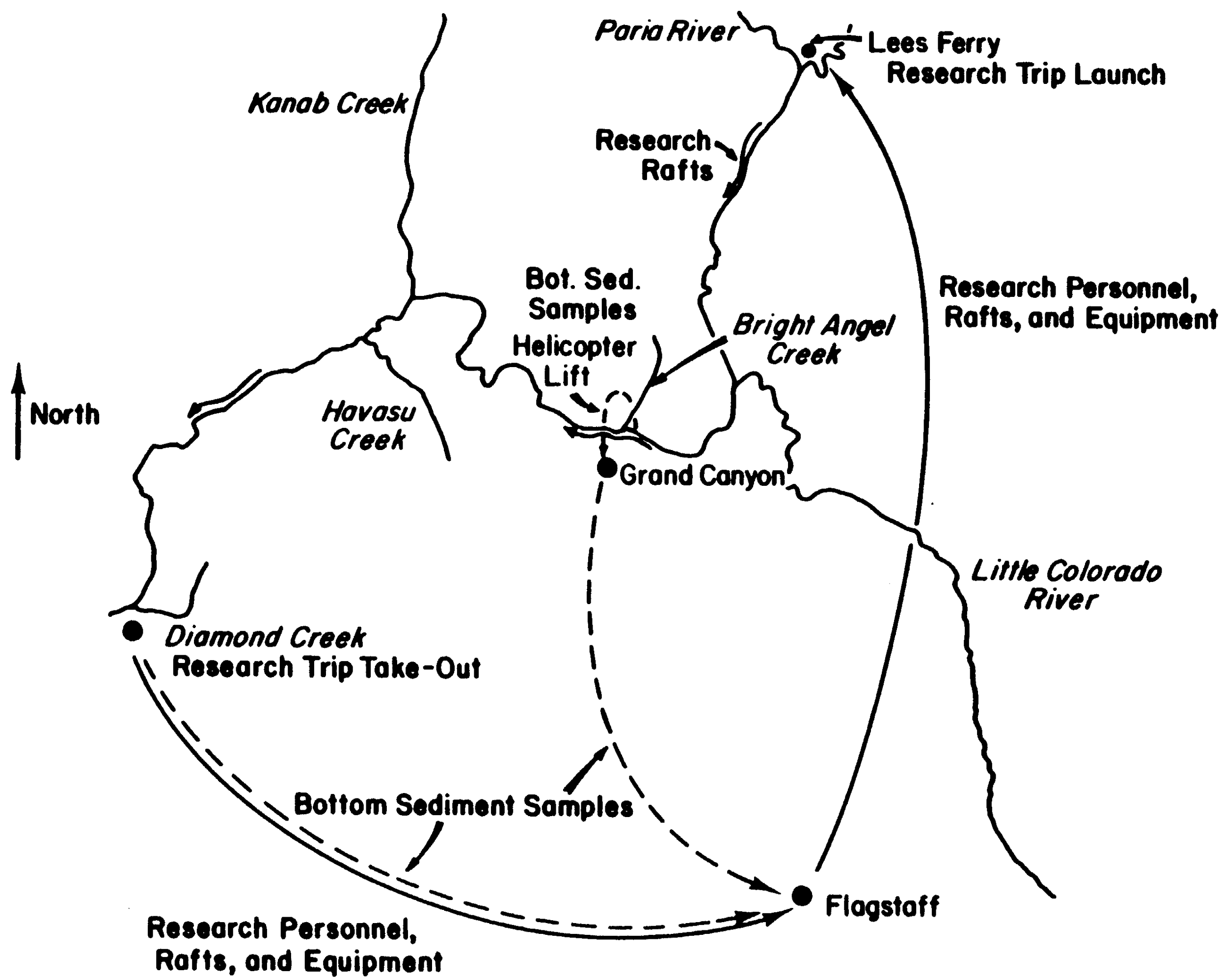


Figure 3. Grand Canyon Research Logistics.

KEY

1. Kick Board
2. Sample Gear
3. Library
4. Personal Gear
5. Boat Pump
6. MPN 35°C Incubator & Battery
7. MF Incubator Battery & Lab Supplies
8. UV Sterilization Box
9. Seat
10. Ice Chest 210lbs of Ice, Food, & Samples
11. Chem Lab
12. Stove Propane Tank
13. Lab Filtration
14. Tool Kit
15. First Aid
16. Toilet
17. Stove
18. Kitchen
19. Food
20. Generator
21. Splash Shield
22. Inflatable Neoprene Rubber Pontoon
23. Aluminum Frame
24. Spare Oar

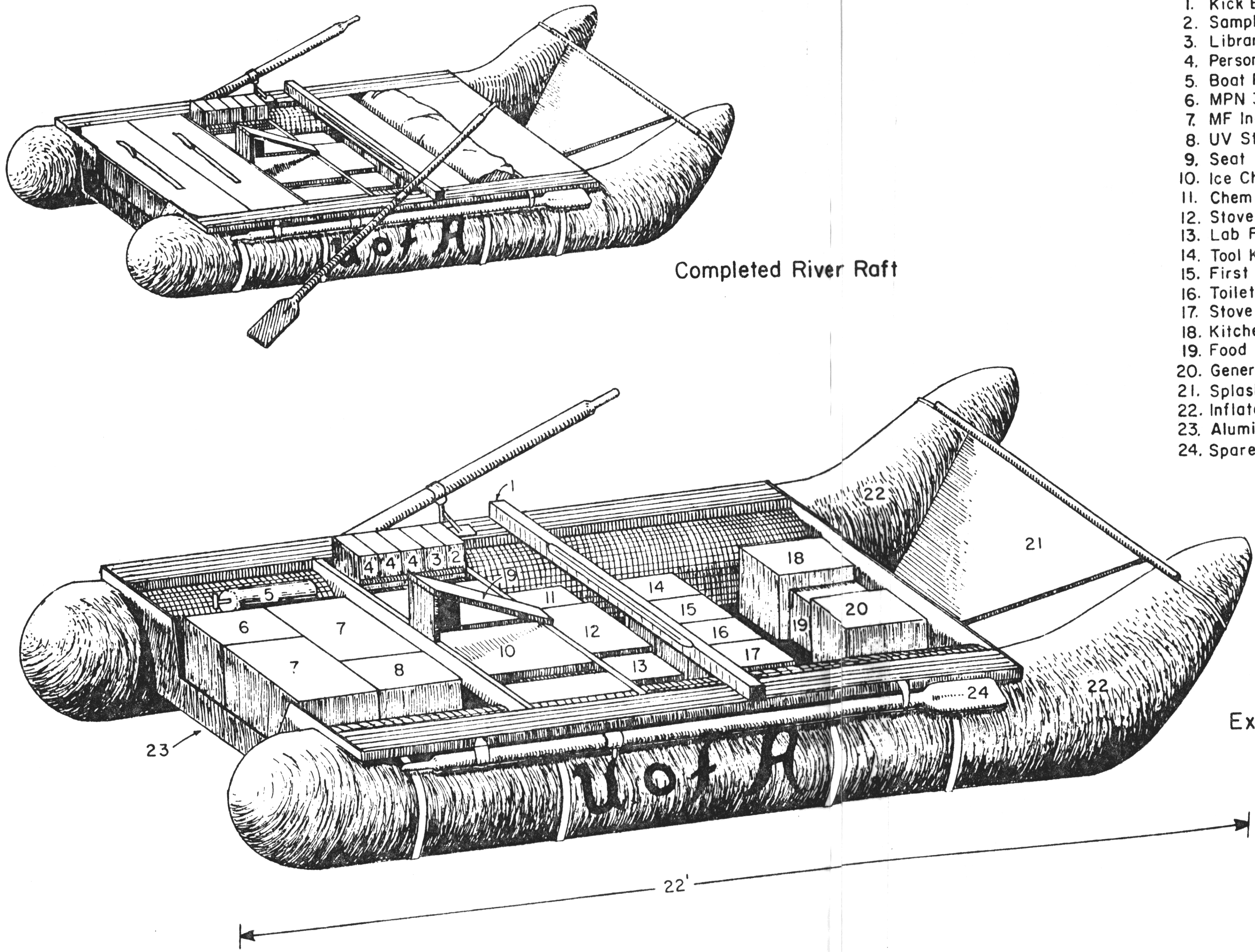


Figure 4. Colorado River Research Raft Design.

of this study. Actual sample designs and sample site selection were an integration of the stated objectives with consideration for characteristics of the river corridor environment, water use behavior patterns of river runners, and logistical constraints of operating in Grand Canyon.

1. Colorado River Sample Program

The Colorado River through Grand Canyon is complex in terms of water quality analyses. Cross channel current irregularities, water level regulation by Glen Canyon Dam, tributary inputs to the river, and variations in bottom sediment distributions create a potential variety of microbial habitats and inputs within the Colorado River-Grand Canyon system. As well, use intensities vary among Colorado River beaches; accordingly, associations between visitor use and water quality may also be diverse. To adequately determine baseline water quality status of the complex Colorado River system, two sampling approaches were necessary: a) a fixed site sample design and b) a time series sample design.

a. Fixed Site Sample Design

The fixed sample site design (Table 10) was used primarily during 1978 to establish a linear river quality profile and to focus on selected Colorado River features. Forty-six fixed sample sites were established along the 225-mile course of the Colorado River in 1978; 11 of the 1978 sites were resampled in 1979 (Table 11). The purpose of each sample site selection is indicated in Table 12. Detailed information collected at each site was recorded on individual data sheets (Figure 5).

Most fixed sample sites have been located in association with river features such as tributary confluences, attraction sites, or camping beaches to meet research objectives; spatially these sites represent a fairly comprehensive linear pattern along the river course. A few sites (Table 12), not associated with selected river features, have been located as periodic samples to complete the linear sampling pattern along the river (River at Cave Springs, River at Vasey's, Tuckup, 205 Mile, and River at Granite Springs). The fixed site design examines the river an average of every 5 miles; the longest interval between samples is 22 miles (National Camp--mile 166--to Whitmore--mile 188); 39 out of 46 sample intervals are less than 10 miles. Six trips in 1978 allowed 6 replications at each sample site, a total of 268* fixed site river samples.

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*(6 trips)(46 sample sites/trip) = 276 samples; however, 8 samples were missed due to logistical and procedural field problems; the actual total = 268.

Table 10. Characteristics of Fixed Site and Time Series Sample Designs.

Characteristic	Fixed Site Sample Design	Time Series Sample Design
Purpose	Examine surface water and bottom sediment quality of selected locations and environments of the Colorado River. Research objectives orient this design to potential problem areas for river runners.	Determine composite surface water quality of the Colorado River; oriented towards "average" water quality of the river, not problem areas.
Site selection	Directed by research objective to select sites which examine specific water quality phenomena (e.g., tributary inflows) or water quality-recreational use associations (e.g., bottom sediment quality at camping beaches.	Function of time and travel progress; surface water sample collected at 0800, 1200, and 1800 hrs each day of travel on the river from the research raft regardless of location on the river.
Sample interval-linear space between samples	Not uniform but fixed for all research trips.	Variable from trip to trip.
Time between samples	Variable.	Fixed.
Sample numbers per day	Variable; function of travel distance and number of fixed sites passed. Range 1 to 8.	Fixed; 3 per day regardless of travel distance.
Sample numbers per trip	Fixed; 46 per trip.	Variable; (3/day)(days/trip) = samples per trip. Average 1978: 36 per trip.
Replications (1978) per trip	Site specific; 1 per site;	Non-site specific; 36 per trip composite.
Replications (1978) per season (6 trips)	Site specific; 6 per site.	Non-site specific; 218 per season composite.
Parameters measured	Surface water fecal coliforms, stir sample fecal coliforms (1979 only), bottom sediment fecal coliform, surface water fecal streptococcus (1978 only), physical, chemical.	Surface water fecal coliforms at 0800, 1200, and 1800, surface water fecal streptococcus at 1200 (1978 only), physical.

Table 11. Grand Canyon Colorado River Fixed Sample Sites.

1978		Sample(s) Taken				1979		Sample(s) Taken		
Site Name	River Mile Location	FC-Surface[1]	FS-Surface[2]	FC-Bottom Sediments[3]	Chemistry	Site Name	River Mile Location	FC-Surface	FC-Stir[4]	FC-Bottom Sediments
Lees Ferry*	0.0	X	X	X	X	Lees Ferry*	0.0	X	X	X
Below Paria**	0.9	X	X							
Navajo Bridge**	4.5	X	X							
Above Badger*	7.7	X		X						
Above House Rock*	17.0	X								
River at Cave Springs**	26.0	X								
River at Vaseys*	32.0	X								
Redwall*	33.0	X		X	X	Redwall*	33.0	X		X
Buckfarm*	41.0	X								
Nankoweep Camp*	52.7	X	X	X	X					
Above Little Colorado*	61.4	X				Above Little Colorado*	61.4	X		
Below Little Colorado**	62.0	X	X			Below Little Colorado**	62.0	X		
Tanner*	69.0	X	X	X						
Unkar*	72.6	X	X	X		Unkar*	72.6	X	X	X
Above Clear Creek*	83.9	X	X	X						
Above Bright Angel*	87.4	X	X	X	X	Above Bright Angel*	87.4	X	X	X
Below Bright Angel*	88.8	X	X	X						
Monument Camp*	93.4	X	X	X						
Above Boucher*	96.4	X	X							
Above Crystal*	98.0	X		X						
Tuna**	100.0	X								
Above Shinumo*	108.4	X	X	X	X	Above Shinumo*	108.4	X	X	X
Below Shinumo*	108.9	X	X							
Above Elves*	116.4	X								
Below Elves**	117.0	X								
Above Stone*	131.9	X	X		X					
Below Stone*	132.1	X	X	X		Below Stone*	132.1	X	X	X
Above Tapeats*	133.3	X	X							
Above Deer*	136.1	X		X						
Below Deer***	136.8	X								
Above Kanab*	143.3	X		X						
Below Kanab*	143.5	X								
Below Matkatamiba**	148.0	X								
Above Havasu***	156.5	X	X							
Below Havasu(1)*	156.8	X				Below Havasu(1)*	156.8	X		
Below Havasu(2)**	157.0	X								
Below Havasu(3)**	157.2	X	X			Below Havasu(3)**	157.2	X		

Table 11.--continued.

1978						1979				
		Sample(s) Taken						Sample(s) Taken		
Site Name	River Mile Location	FC-Surface[1]	FS-Surface[2]	FC-Bottom Sediments[3]	Chemistry	Site Name	River Mile Location	FC-Surface	FC-Stir[4]	FC-Bottom Sediments
Tuckup**	164.4	X	X							
National Camp*	166.0	X	X	X	X	National Camp*	166.0	X	X	X
Whitmore*	188.0	X		X						
193 Mile*	193.0	X		X						
205 Mile**	205.0	X								
Granite Park**	209.0	X	X	X						
River at Granite Springs*	220.5	X								
Above Diamond*	225.3	X	X	X						
Below Diamond*	225.5	X								
TOTALS		46	23	20	8			11	6	7

[1]FC-Surface: Fecal coliform densities measured in surface water sample.

[2]FS-Surface: Fecal streptococcus densities measured in surface water sample.

[3]FC-Bottom Sediments: Fecal coliform densities measured in bottom sediment sample.

[4]FC-Stir: Fecal coliform densities measured in stir sample.

*Sample site at river bank--31 sites (1978).

**Sample site at midstream--14 sites (1978).

***Sample site varied from river bank to midstream--2 sites (1978).

Table 12. Purpose of Colorado River Fixed Sample Site Selections.

Site Name (River Mile)	Purpose of Selection
Lees Ferry (0.0)*	Initial sample establishes base quality level of river water entering Grand Canyon study area; downstream limit of intensively used Lees Ferry to Glen Canyon Dam river segment; intensively used beach.
Lees Ferry (0.0)* Below Paria (0.9)**	Brackets Paria River inflow influence.
Navajo Bridge (4.5)**	Establish base quality level of river water entering Grand Canyon.
Above Badger (7.7)*	Establish base quality.
Above House Rock (17.0)*	Establish base quality.
River at Cave Springs (26.0)**	Periodic sample of Colorado River.
River at Vasey's (32.0)*	Periodic sample.
Redwall (33.0)*	Intensively used beach area.
Buckfarm (41.0)*	Periodic sample; camping beach.
Nankoweep Camp (52.7)*	Periodic sample; camping beach.
Above Little Colorado (61.4)*	Periodic sample.
Above Little Colorado (61.4)* Below Little Colorado (62.0)**	Brackets Little Colorado.
Tanner (69.0)*	Periodic sample; backpack area.
Unkar (72.0)*	Intensively used camping beach.
Above Clear Creek (83.9)*	Periodic sample.
Above Clear Creek (83.9)* Above Bright Angel (87.4)*	Brackets Clear Creek
Above Bright Angel (87.4)* Below Bright Angel (88.8)*	Brackets Bright Angel Creek.
Below Bright Angel (88.8)* Monument Camp (93.4)*	Brackets Garden Creek.

Table 12.--continued.

Site Name (River Mile)	Purpose of Selection
Monument Camp (93.4)*	Periodic sample; backpack and camping area.
Monument Camp (93.4)* Above Boucher (96.4)*	Brackets Monument and Hermit Creeks.
Above Boucher (96.4)* Above Crystal (98.0)*	Brackets Boucher Creek.
Above Crystal (98.0)* Tuna (100.0)**	Brackets Crystal Creek.
Tuna (100.0)**	Periodic sample.
Above Shinumo (108.4)*	Periodic sample.
Above Shinumo (108.4)* Below Shinumo (108.9)*	Brackets Shinumo Creek.
Above Elves (116.4)* Below Elves (117.0)**	Brackets Royal Arch Creek.
Below Elves (117.0)**	Periodic sample.
Above Stone (131.9)*	Periodic sample.
Above Stone (131.9)* Below Stone (132.1)*	Brackets Stone Creek.
Below Stone (132.1)*	Camping beach.
Above Tapeats (133.3)*	Camping beach.
Above Tapeats (133.3)* Above Deer (136.1)*	Brackets Tapeats Creek.
Above Deer (136.1)* Below Deer (136.8)* **	Brackets Deer Creek.
Above Kanab (143.3)*	Periodic sample.
Above Kanab (143.3)* Below Kanab (143.5)**	Brackets Kanab Creek.
Below Kanab (143.5)**	Periodic sample.

Table 12.--continued.

Site Name (River Mile)	Purpose of Selection
Below Kanab (143.5)** Below Matkatamiba (148.0)**	Brackets Olo and Matkatamiba Creek.
Above Havasu (156.5)**	Periodic sample.
Above Havasu (156.5)*** Below Havasu 1 (156.8)* Below Havasu 2 (157.0)** Below Havasu 3 (157.2)**	Brackets Havasu Creek, monitors downstream influences of Havasu inflow.
Tuckup (164.4)**	Periodic sample.
National Camp (166.0)*	Camping beach.
Whitmore (188.0)*	Periodic sample; camping beach.
193 Mile (193.0)*	Camping beach.
205 Mile (205.0)**	Periodic sample.
Granite Park (209.0)*	Camping beach.
River at Granite Springs (220.5)**	Periodic sample.
Above Diamond (225.3)*	Final bottom sediment.
Above Diamond (225.3)** Below Diamond (225.5)**	Brackets Diamond Creek.
Below Diamond (225.5)**	Final sample establishes quality level of river water leaving Grand Canyon study area.

*Sample site at river bank.

**Sample site at midstream.

***Sample site varied from river bank to midstream.

Colorado River/Grand Canyon Water Quality Research

Sample Taken By: Date: Time:

Site Name: Number: Mile/Location:

Sample Taken: FC______ FS______ BS______ Stir______ Chem______

Air Temp: H_2O Temp: pH: TDS: Turbidity:

FLOW

☐ Midstream	☐ Left Bank	☐ Right Bank
☐ Top of Rapid	☐ Bottom of Rapid	☐ In Rapid
☐ Top of Eddy	☐ Bottom of Eddy	☐ In Eddy
☐ Upstream Flow	☐ Downstream Flow	☐

Special Weather Phenomena:

CHEMISTRY (Chem Sites Only)

SO_4 ______	Alkalinity	Pheno ______	Phosphate	Ortho ______
NO_3 ______		Total ______		Total ______
Cl ______	Hardness	Ca ______		
		Total ______		

Sample Type	Dilution	Index
MFC		
MFS		
MPN		
____MFC		
____Tubes + MFC		
Stir		
____MFC		
____Tubes + MFS		

Figure 5. Grand Canyon Field Notebook Data Sheet

b. Time Series Sample Design

With an average flow rate of 4.5 mph, Colorado River water has a residency time of about 50 hours in the 225-mile distance from Lees Ferry to Diamond Creek. This fast and continual renewal of water in the river channel suggests that surface water quality status may change significantly over relatively short time intervals.

A time series sample design was used during 1978 and 1979 to detect short interval changes in river water quality. Three samples were collected daily from the Colorado River at the location of the research rafts at 0800, 1200, and 1800 hrs; these hours were selected to monitor water quality through the daylight period when float trip participants make use of river water. A wide variety of river conditions are sampled by this process; river water levels and flow characteristics change continually as do the positions of the research raft from sample period to sample period.

The oar-powered research rafts travel on the current but at a slower rate of progress; time loss occurs with stops, as for fixed site sampling and deviations out of the main current into eddies. As a result, the river moves past the rafts and samples collected at progressive time intervals are from new units of downstream flow.

Time series samples were complemented by the same physical site qualities as fixed site samples (Figure 5).

2. Tributary Sampling Program

Tributaries are important water resources in the Colorado River corridor, representing recreational playgrounds for most river runners and drinking water sources for some. Low volume flows and intensive use of some tributary watersheds suggest that water quality hazards may be associated with the use of some side creeks. Fixed sample sites were established in 1978 on 26 tributaries of the Colorado River to determine baseline water quality of side creeks; nine tributaries were resampled in 1979. Tributary characteristics and sample sites are identified in Table 13.

Chemical concentrations, FC and FS densities, and physical qualities of surface waters and FC densities in bottom sediments were measured in 1978. With baseline data established, 1979 brought a reduction in tributary sites as only critical locations were resampled; fecal streptococcus and chemical analyses were eliminated, and stir samples were introduced into the sampling program.

Each tributary sample site was sampled once per float trip, six replications per site in 1978 and two replications per site in 1979. Time of day, flow rates, current weather, and current recreational use

Table 13. Grand Canyon Tributary Water Quality Sample Sites.

Site Name 1978	Site Name 1979	River Mile	Samples Taken: FC-Surface[1]	FS-Surface[2] (1978 only)	FC-Bottom Sediment[3]	FC-Stir[4] (1979 only)	Chem[5] (1978 only)	Description
Paria River		0.8	X		X		X	Site below Lees Ferry access bridge. Major tributary, perennial flow.
Vasey's Spring		32.0	X	X			X	Site 30 feet from mouth. Spring emanating from redwall limestone.
Nankoweep Creek		52.7	X	X	X		X	Site 100 feet from mouth. Low intensity use by river runners. Flow may be intermittent in dry periods.
Little Colorado River	Little Colorado River	61.5	X	X	X	X	X	Site 400 feet from mouth, north bank. Major attraction site, high intensity use, perennial flow.
Clear Creek		84.0	X		X		X	Site 100 feet from mouth. Float trip and hiker use, perennial flow.
Bright Angel Creek	Bright Angel Creek	87.9	X	X	X[6] (1978 only)	X	X	Site below campground footbridge. Intensive hiker use, pack mules along east bank, perennial flow.
Garden Creek		88.9	X	X	X		X	Site at Bright Angel trail crossing. Hiker use, pack mule crossing, perennial flow.
Monument Creek		93.5	X				X	Site 300 feet from mouth. Hiker use, flow may be intermittent in dry periods.
Upper Hermit	Upper Hermit	94.8	X		X (1978 only)			Site about 3 miles from river above designated campground. Hiker use immediately downstream, flow perennial.
Middle Hermit	Middle Hermit	94.8	X	X	X	X (1979 only)		Site at pool in campground about 200 feet below Upper Hermit site. Intensive hiker use, leach field toilet in campground, flow perennial.
Lower Hermit	Lower Hermit	94.8	X		X			Site below campground about 500 feet below Middle Hermit site. Intensive hiker use, flow perennial.
Hermit at River	Hermit at River	94.8	X	X	X		X	Site 30 feet from mouth, intensive hiker use, flow perennial.

Table 13.--continued.

Site Name 1978	Site Name 1979	River Mile	Samples Taken: FC-Surface[1]	FS-Surface[2] (1978 only)	FC-Bottom Sediment[3]	FC-Stir[4] (1979 only)	Chem[5] (1978 only)	Description
Boucher Creek		96.5	X		X		X	Site 100 feet from mouth. Hiker use, flow may be intermittent in dry periods.
Crystal Creek		98.1	X		X		X	Site 200 feet from mouth. Little use, flow perennial.
Shinumo Creek	Shinumo Creek	108.5	X		X (1978 only)		X	Site 300 feet from mouth, pool below falls. Intensive float trip use, flow perennial.
Upper Elves Chasm	Upper Elves Chasm	116.5	X		X	X		Site at pool below first major falls. Intensive float trip use, flow perennial.
Lower Elves Chasm		116.5	X				X	Site top of falls just above river. Intensive float trip use, flow perennial.
Stone Creek		132.0	X		X		X	Site 400 feet from mouth. Float trip use, flow may be intermittent in dry periods.
Tapeats		133.4	X	X	X		X	Site 100 feet from mouth. Float trip and hiker use, flow perennial.
Upper Deer Creek		136.2	X		X			Site above falls at entrance to upper valley. Float trip use, hiker use, flow perennial.
Lower Deer Creek	Lower Deer Creek	136.2	X		X	X	X	Site at pool below falls. Intensive float trip use, hiker use, perennial flow.
Kanab Creek	Kanab Creek	143.4	X	X	X (1978 only)		X	Site 100 feet from mouth. Light float trip use, hiker use, flow perennial.
Olo Creek		145.5	X		X			Site at pool above creek mouth. Float trip use, flow perennial.
Matkatamiba	Matkatamiba	147.7	X		X (1978 only)		X	Site about 400 yards from mouth above narrows. Float trip use, flow perennial.
Upper Havasu		156.8	X	X	X			Site about 1 mile from mouth. Intensive float trip, hiker, and Indian use upstream. Flow perennial.
Middle Havasu	Middle Havasu	156.8	X		X	X	X	Site about 400 yards from mouth of major pool. Intensive float trip use, hiker use, flow perennial.

Table 13.--continued.

Site Name 1978	Site Name 1979	River Mile	Samples Taken: FC-Surface[1]	FS-Surface[2] (1978 only)	FC-Bottom Sediment[3]	FC-Stir[4] (1979 only)	Chem[5] (1978 only)	Description
Lower Havasu	Lower Havasu	156.8	X					Site about 100 yards from mouth at trail ford. Intensive float trip use, hiker use, flow perennial.
National Canyon		166.0	X				X	Site about 400 yards from mouth at boulder constriction. Low float trip use, flow may be intermittent in dry periods.
Fern Glen		168.0	X		X		X	Site about 500 yards from mouth below boulder constriction. Low float trip use, flow may be intermittent in dry periods.
Mohawk Creek		171.4	X				X	Site about 1 mile from mouth. Flow may be intermittent.
Pumpkin Spring		212.1	X				X	Site at Pumpkin Spring. Float trip use.
Three Springs		215.5	X				X	Site about 200 feet from mouth. Float trip use, flow perennial.
Diamond Creek		225.4	X		X		X	Site about 300 feet from mouth. Day use, Indian use upstream, road crossings, flow perennial.

[1]Fecal coliform densities measured in surface water sample.

[2]Fecal streptococcus densities measured in surface water sample.

[3]Fecal coliform densities measured in bottom sediment sample.

[4]Fecal coliform densities measured in stir sample.

[5]Chemistries.

[6]Flood flow scoured Bright Angel sediment at sample site precluding bottom sediment sampling in 1979.

varied at each site from sample period to sample period. Multiple sites were established on Hermit Creek, Elves Chasm (Royal Arch Creek), Deer Creek, and Havasu Creek in response to dispersed and intensive recreational activities along the streams' reaches.

D. FIELD ANALYSIS PROCEDURES

Bacteriological, chemical, and physical water quality analyses were performed in the Grand Canyon field environment; parameters measured and the corresponding analytic methodologies were identified in Table 9 (Section III.C). Analytical techniques were predominantly of standard design (Table 9). Modifications of some bacteriological techniques and apparatus were necessary to adapt to the Canyon situation; these procedures have been discussed following in this section. Chemical and physical water quality determinations were standard procedures; Table 9 references are adequate descriptors of these procedures and further elaboration has not been included.

1. Sample Collection and Storage

All Grand Canyon water quality samples were collected in sterile Whirl Pak brand polyethylene bags and stored on ice until analyses. Surface water sampling, including bacteria, chemistry, and stir samples, required 500 ml capacity Whirl-Paks; bottom sediment samples were placed in 250 ml capacity bags.

Surface water samples were taken from approximately the top six inches of water depth. Samples were collected with an opened Whirl-Pak bag in a scooping motion against the current at the sample site. Bags were immediately sealed and placed on ice.

Duplicate bottom sediment samples were collected at selected fixed sites in conjunction with a surface water sample; bottom sediment collection followed surface water sampling to avoid contaminating surface samples with sediment. Sediments were taken from the top two inches of bottom material within 1.5 feet of the shoreline in water about six inches deep. A small (3 inch) open trough scoop disinfected with EtOH was used to collect sediments. Bottom sediments were stored on ice for up to 10 days in 1978; each duplicate sample was double-bagged for durable protection during storage.

Stir samples were taken at selected sites following bottom sediment sampling. A sediment cloud was suspended in the overlying surface water by stirring the bottom material with the sediment scoop. A stir sample was taken from the sediment-clouded water using the surface water sampling technique.

2. Surface Water Sample Analysis

Fecal coliform and fecal streptococcus densities in surface water samples were determined with membrane filter (MF) methodologies. Using MF technique, a sample was drawn by vacuum through an appropriately sized sterile MF which entrapped the bacteria on the filter surface. The filter was placed on a selective medium within a sterile petri dish (MF plate) and incubated for a specific time and temperature to culture individual bacteria to visible colony size for identification and enumeration. The numbers of colonies per MF plate were assumed to be equivalent to the number of bacteria in the volume of sample filtered.

As an analytical procedure, the MF system was sectioned into five components for field adaptation as well as for the following discussion: a) analytical design; b) sample filtration; c) media preparation; d) sample incubation; and e) apparatus sterilization. Field analyses performed with the MF system met all of the Standard Methods (1975) criteria for the methods.

a. Analytical Design

Determining indicator bacteria densities via MF technique requires scaling of the filtered sample volume to produce an MF plate with colony numbers in a countable range (FC--20 to 60 colonies per plate; FS--20 to 100 colonies per plate (EPA, 1978)). Surface water FC and FS densities were expected to be low in the Colorado River system of Grand Canyon based on previous research (as reported in NPS, 1979a) and experience with other natural watersheds in Arizona (Utter, 1975; Motschall, 1976; and Patterson, 1977). Accordingly, research was initiated filtering surface water sample volumes from the Colorado River and side creeks of 10 ml, 50 ml, and 100 ml for both the FC and FS tests.

Except on occasions, FC densities in the river and side creeks were below the countable range for sample volumes of 100 ml. Filtered sample volumes could have been increased to produce countable plates; this option was rejected. The numbers of samples were large enough and repetitive results clearly define the low range of FC densities. Filtered volumes in excess of one liter would have been necessary to guarantee countable plates, an investment of research time and materials which would not be balanced by significantly more accurate pictures of FC densities.

Densities of FS bacteria were usually found in the countable range with the 10 ml, 50 ml, and 100 ml sample volumes.

Samples of FC or FS bacteria which were below countable range were calculated as follows:

$$\text{Bacteria Density/100 ml} = \left(\frac{\text{\# of bacteria on all plates}}{\text{Total volume filtered on all plates}} \right) \times (100 \text{ ml})$$

b. Sample Filtration

Research began in 1978 using two syringe-type Millipore brand hand vacuum pumps, filter flasks, and Millipore stainless steel filter funnels and bases. The system was cumbersome,but two operators could accurately process up to 24 samples in two hours. In 1979, a new filtration system was devised using a high volume "Guzzler 400" marine bilge pump as a hand-powered vacuum source, a volume tank constructed of 4-inch PVC pipe, a Millipore three-place vacuum manifold, and Gelman magnetic Lexan plastic filter funnels and bases. Quick, uniform field processing of samples with the new system expanded the daily sampling capabilities of the field unit.

Samples were vigorously shaken in the sealed Whirl-Paks prior to filtration to distribute bacteria uniformly and to dislodge potential clumps of bacteria. Filter volumes were poured directly from the Whirl-Pak into sterile graduate cylinders for measurement. Gelman type GN-6 0.45 μm sterilized membrane filters were used for FC and FS analyses. Sterile, disposable Falcon and Millipore MF petri plates were the incubation vessels. Sample filtration was followed with a rinse of the filter funnel with sterile, buffered water to dislodge any bacteria from the funnel side.

Turbidities in the Colorado River and side creeks were usually low enough that suspended sediment did not accumulate on filters. When sediment loads became excessive, filter volumes were split into smaller units, processed on separate filters, and counted collectively (e.g., 100 ml filter volume became 4 x 25 ml or if necessary 10 x 10 ml). The split sample process adequately reduced sediment loads.

c. Medium Preparation

Fresh culture medium was routinely prepared in the Canyon. Dehydrated medium was preweighed and sealed in air- and watertight containers prior to each trip in amounts to make 100 ml volumes of liquid medium. Fecal coliform bacteria were cultured on M-FC broth; FS bacteria were cultured on KF-Streptococcus agar. M-FC broth was prepared every 24 to

48 hours and stored in the preparation flask in the ice chests for pouring when needed. Gelman pure cellulose fiber pads held the medium in the petri plates. KF agar plates were poured in advance and held up to 72 hours in ice chests before being discarded.

d. Sample Incubation

Membrane filter plates were incubated in Millipore aluminum block MF petri dish incubators. Power was supplied by 12-volt 95-ampere-hour truck batteries. An incubator and a battery were secured in a watertight aluminum military radio box to form a unit capable of precise, continuous incubation for up to 8 days without recharge. A Honda 400 generator provided recharge when needed. Four complete incubation units were carried in the Canyon, with a capacity to culture 120 MF plates at one time.

e. Apparatus Sterilization

Filtration funnels and graduate cylinders used to measure sample volumes were sterilized between sample runs with an ultraviolet light box constructed in a military field radio box from a 12-volt 95-ampere-hour truck battery, a fluorescent lamp fixture, and germicidal UV lamps.

3. <u>Bottom Sediment Analyses</u>

Enumeration of FC bacteria in bottom sediment was accomplished with the multiple fermentation tube method (commonly referred to as the most probable number method or MPN). MPN is a stepwise process; positive bacteria occurrences from presumptive test fermentation tubes are transferred to confirmatory test fermentation tubes to verify FC presence. Bacterial densities are quantified through a probability table relating the occurrence of FC bacteria in a replicated matrix of fermentation tubes inoculated with serial dilutions of sample to sample FC densities. Bacteria are cultured in suspensions in a broth medium and their presence is detected by the production of gas trapped in an inverted vial; sediment is usually not an interference.

Conventionally applied, MPN was too cumbersome for practical field use; two separate sets of fermentation tubes, two media, and two incubation temperatures are required for the standard procedure (<u>Standard Methods</u>, 1975). Bottom sediment analyses could not be performed with the MF technique as there was no way to eliminate sediment from the filters without removing bacteria adhering to the substrate from the sample population. Consequently, in 1978 bottom sediment samples were stored

SECTION IV

DATA PRESENTATION AND STATISTICAL RESULTS

A. GRAND CANYON CLIMATIC DATA
B. PHYSICAL WATER QUALITY DATA
   1. Stream Flow
   2. Water Temperature
   3. Turbidity
C. CHEMICAL WATER QUALITY DATA
   1. Colorado River
   2. Colorado River Tributaries
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      b. Orthophosphate and Nitrate-Nitrogen
      c. Chloride and TDS
D. BACTERIAL WATER QUALITY DATA
   1. 1978 Colorado River Data
      a. 1978 River Surface Water FC Densities
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      c. 1978 River Bottom Sediment FC Densities
   2. 1979 Colorado River Data
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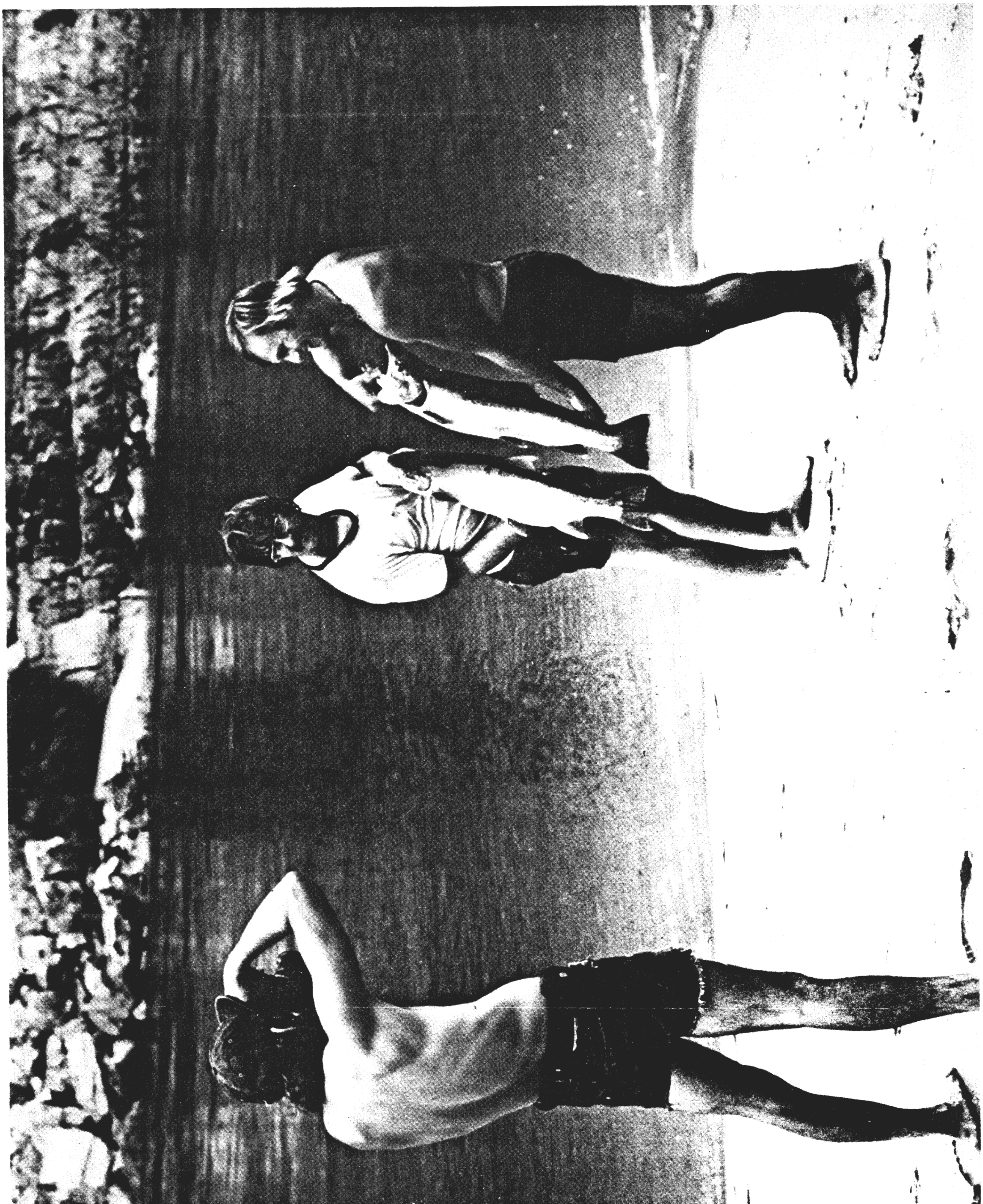
   4. 1979 Tributary Data
   5. 1979 Stir Sample Data
E. STATISTICAL RESULTS
   1. Fecal Coliform Distributions in the Colorado River
   2. Fecal Coliform Densities in Surface Waters and Bottom Sediments



IV. DATA PRESENTATION AND STATISTICAL RESULTS

A host of environmental factors interact to determine water quality status; climatic and hydrological regimes have important influences on bacterial water quality conditions of the Colorado River corridor. Selected climatic and hydrological data are presented in this section along with bacterial data to provide a comprehensive water quality perspective. Section IV is divided into: A) Grand Canyon climatic data; B) physical water quality data; C) chemical water quality data; D) bacterial water quality data; and E) statistical results.

A. GRAND CANYON CLIMATIC DATA

Seasonal precipitation and temperature regimes, April through September, 1978, for the Grand Canyon region have been reviewed based on monthly means from five climatic stations located in the region. Grand Canyon and Bright Angel Ranger Stations were located on the south and north rims opposite mile 88 at elevations of 6950 ft. and 8400 ft. respectively. Lees Ferry (mile 0) and Phantom Ranch (mile 88) were located on the canyon floor at elevations of 3210 ft. and 2570 ft. respectively. Supai was situated in Havasu Canyon (mile 157) at an elevation of 3205 ft. approximately 8 miles from the Colorado River.

Normal seasonal temperatures were experienced in the Grand Canyon region (Figure 6). Near-normal precipitation fell at Grand Canyon during the early research period, but markedly dry conditions (Figure 7) prevailed during most of the normal summer monsoon season (July-September). As a result of below-normal rainfall, tributary watershed flushing, which could have significant impacts on tributary and river water quality, was uncommon during summer 1978.

The 1979 research period, July through the first half of August, was also characterized by seasonal temperatures but below average rainfall.

B. PHYSICAL WATER QUALITY DATA

Physical water quality parameters examined by the research are: 1) stream flow, 2) water temperature, and 3) turbidity. United States Geologic Survey (USGS) collected stream flow data; water temperature and turbidity were measured on site by the University of Arizona.

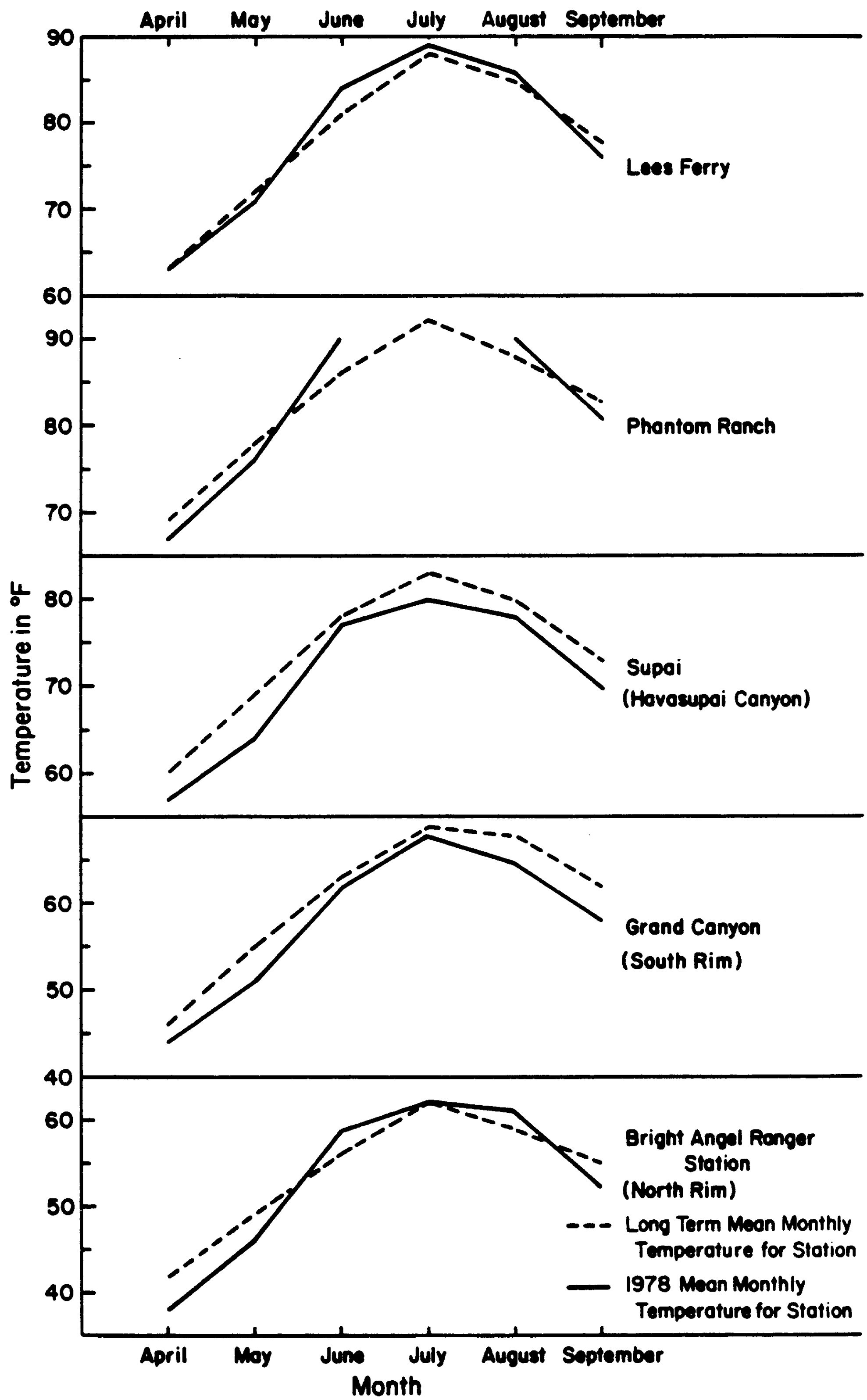


Figure 6. Seasonal Temperatures in the Grand Canyon Region.

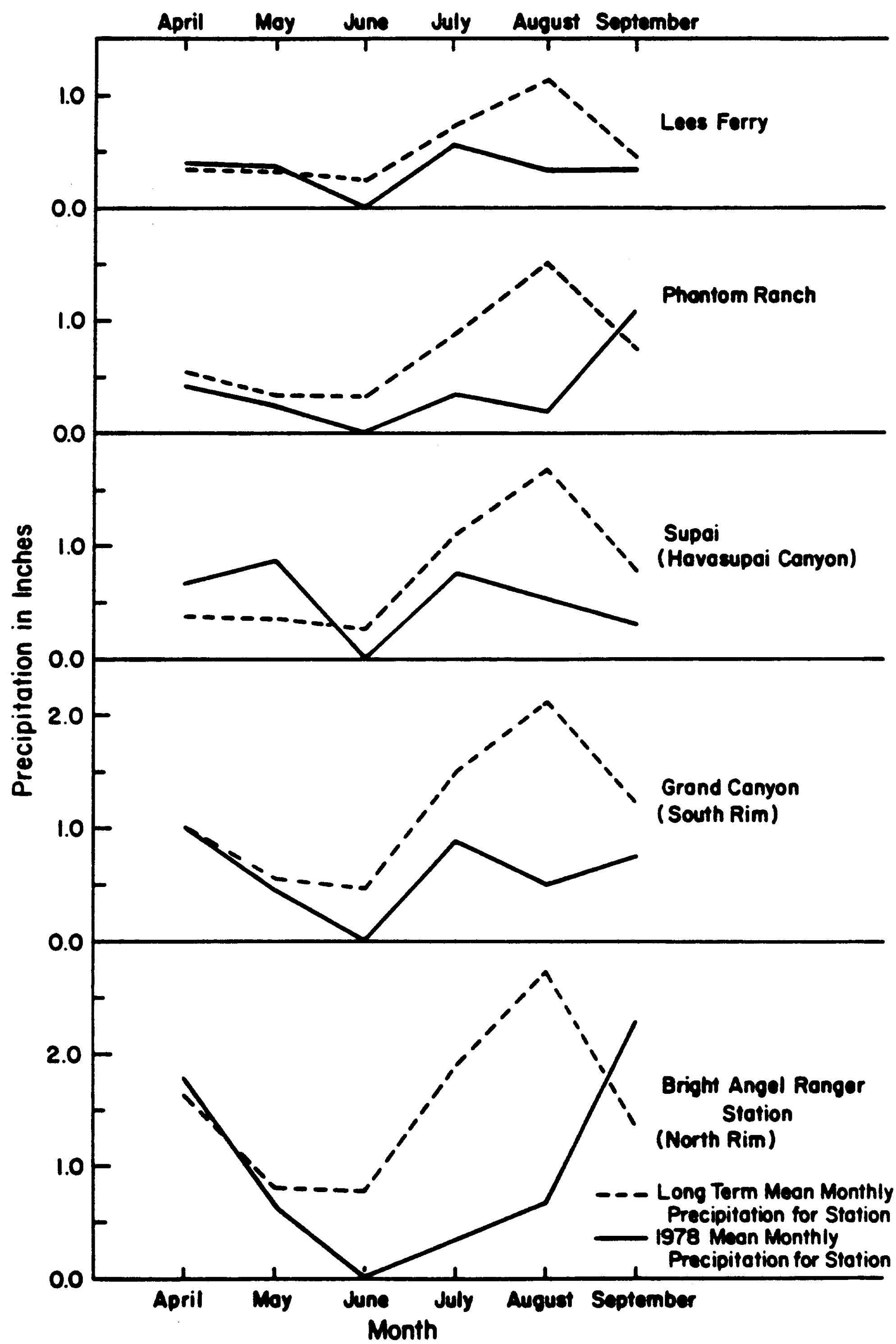


Figure 7. Seasonal Precipitation in the Grand Canyon Region.

1. Stream Flow

Stream flow volume was monitored at USGS gaging stations on the Colorado River at miles 0 and 87 and on three tributaries--Paria River at Lees Ferry; Little Colorado River near Cameron, Arizona; and Kanab Creek near Fredonia, Arizona.

Colorado River stream flow was regulated by Glen Canyon Dam releases. Hydrographs (Figures 8 and 9 for 1978 and 1979, respectively) show daily mean discharge of the river at mile 87 to generally increase during the river running season with peak flows in August and September, a typical Grand Canyon regime. Competence for resuspension of bed load increases with discharge, a process which potentially resuspends microbial contaminants as well as bottom sediment. High volume river flows had a dilution effect on contaminants from external river sources.

Daily releases from Glen Canyon Dam frequently varied dramatically (Figures 8 and 9), a typical process for hydroelectric operations. Fluctuating water levels potentially had impacts on water quality resulting from bottom sediment disturbance and associated resuspensions of sediment concentrations of microbial organisms.

Tributary stream flow data for 1978 reflected the below-normal summer precipitation, decreasing dramatically for the summer period (Table 14).

2. Water Temperature

Water temperatures for 1978 (Figure 10) indicate that river temperatures are a function of the hypolimnion temperature of Lake Powell, river water level (i.e., discharge volume), and distance downstream from the dam. Mean water temperatures increased slowly in the downstream direction, but the downstream temperature profile changed little through the research season. A mean temperature of about 12.9°C, representing 410 river samples from all river locations, had a standard deviation of 2.1, reflecting minor temperature variations.

Temperature variations over short distances were in response to site location and water level fluctuation. Shallow beach sites tended to be a few degrees warmer than mid-channel sites. Minimum temperatures recorded at any given river location were associated with the highest flows; resistance to temperature change is proportional to the volume of water which requires warming.

Tributary temperatures were significantly warmer than the river and showed a seasonal trend (Table 15).

Mean water temperature data for each tributary and river sample site have been listed in Appendix B.

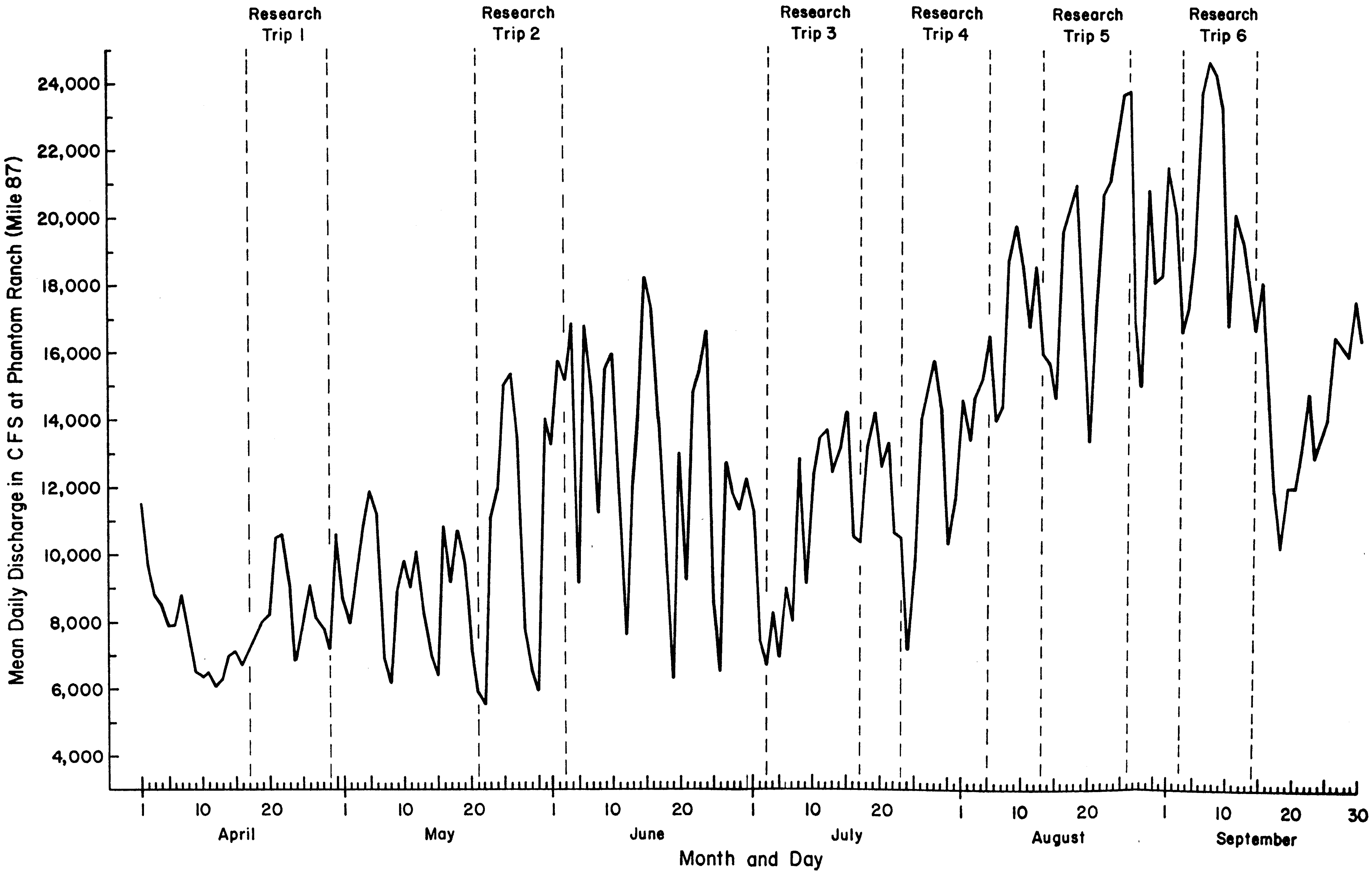


Figure 8. Mean Daily Flow of Colorado River at Phantom Ranch (Mile 87), April through September, 1978.

(Geologic Survey, 1978).

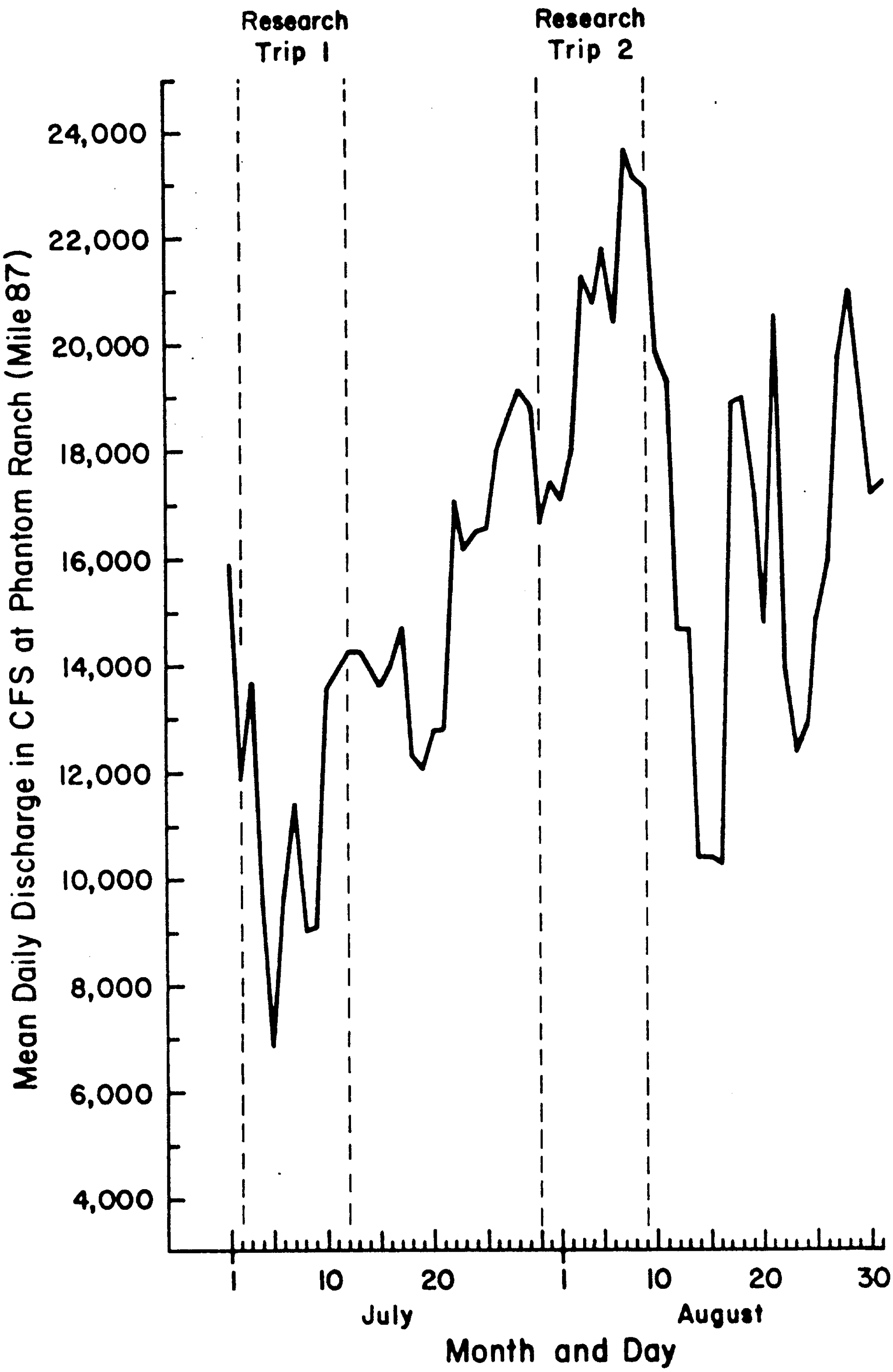


Figure 9. Mean Daily Flow of Colorado River at Phantom Ranch (Mile 87), July and August, 1979.

(Geologic Survey, 1979).

Table 14. Monthly Mean Discharge of the Paria and Little Colorado Rivers and Kanab Creek. Values in cfs.

Tributary	Month					
	April	May	June	July	August	September
Paria River						
Long-term mean*	19.0	9.2	7.5	28.4	64.3	60.8
1978 mean**	32.5	6.7	3.3	5.0	5.5	5.1
Little Colorado River						
Long-term mean	594.0	145.0	25.3	114.0	495.0	243.0
1978 mean	791.0	37.2	3.4	0.0	4.0	20.4
Kanab Creek						
Long-term mean	15.2	0.3	0.1	4.3	9.9	5.3
1978 mean	31.2	0.2	0.0	0.0	2.7	1.9

*Anderson and White, 1979.

**USGS, 1978.

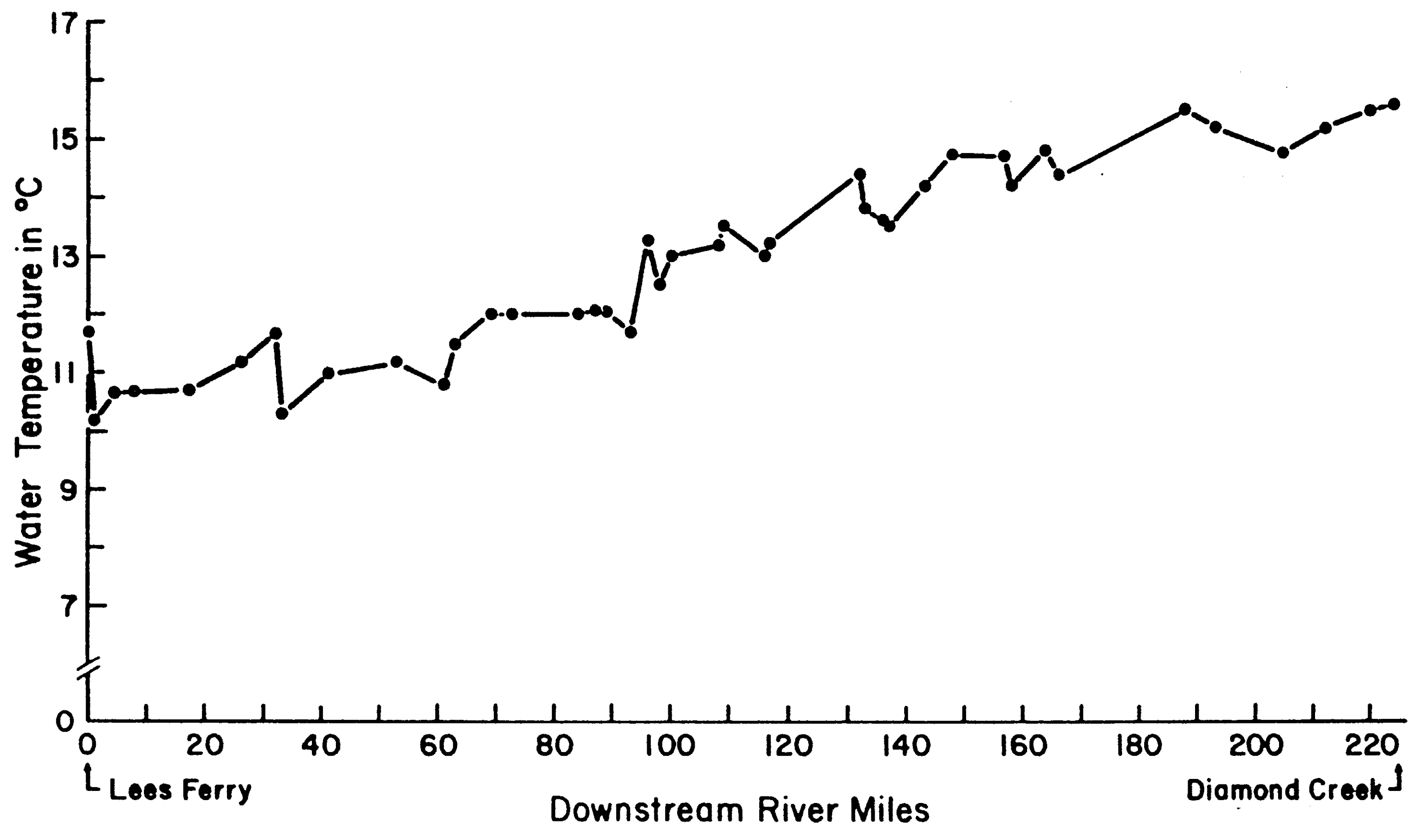


Figure 10. Mean Water Temperature Profile of the Colorado River, April through September, 1978.

Table 15. Mean Tributary Temperatures (°C) by Research Trip in 1978.

Statistic	Trip Number 1	2	3	4	5	6
Sample Number	19	32	31	33	32	29
Mean Temperature (°C)	15.7	20.2	22.9	24.1	22.5	21.3
Standard Deviation	5.22	4.38	4.11	4.34	4.89	3.83

Trip 1. 17-29 April.

Trip 2. 21 May - 3 June.

Trip 3. 3-17 July.

Trip 4. 23 July - 5 August.

Trip 5. 13-26 August.

Trip 6. 3-14 September.

3. Turbidity

Turbidity measurements indexed suspended sediment concentrations in the Colorado River and tributaries. Suspended sediment concentrations and surface water FC densities can be closely associated; consequently turbidity was monitored through the research period.

A special illustrative device was used to display turbidity and indicator bacteria data. Review of these data showed strongly skewed distributions with clustering around the median and the occurrence of some extremely high values. Box and whisker pole plots (Figure 11) provided an ideal illustrative perspective of these distributions, showing the significance of extreme quality events as well as the tendency for predominate turbidity and indicator bacteria densities.

Turbidity data (Figure 12 and Appendix B) showed predominately low suspended sediment concentrations in the Colorado River corridor during 1978 and 1979. High turbidities which did occur were in response to precipitation on Grand Canyon watersheds and/or fluctuating river water levels.

C. CHEMICAL WATER QUALITY DATA

Chemical analyses of the Colorado River and tributaries were conducted in 1978 to provide baseline chemical profiles of the river corridor water resources. Presentation of chemical water quality data has been divided into: 1) Colorado River and 2) tributaries.

1. Colorado River

Chemical concentrations of the Colorado River in 1978 (Table 16) were not detected in amounts unexpected for natural waters and should not cause river recreationists concern.

At a mean pH of 8.2, the river was a well-buffered system as indicated by the stability of the pH ($s = 0.18$, $n = 153$) and the level of alkalinity (mean total alkalinity = 199 mg/l). Low phenolphthalein alkalinity (15 mg/l) relative to total alkalinity (199 mg/l) indicates a predominance of bicarbonate alkalinity, a small proportion of carbonate alkalinity, and essentially zero hydroxide alkalinity.

Dissolved solids have been traditionally high in the Colorado River; a mean total dissolved solids (TDS) value of 563 mg/l for 1978 exceeded U.S. Public Health Drinking Water Standards (1962) of 500 mg/l for sustained consumption. NPS (1979a) has determined that the occasional consumption of high salinity river water by individual recreationists does not warrant concern.

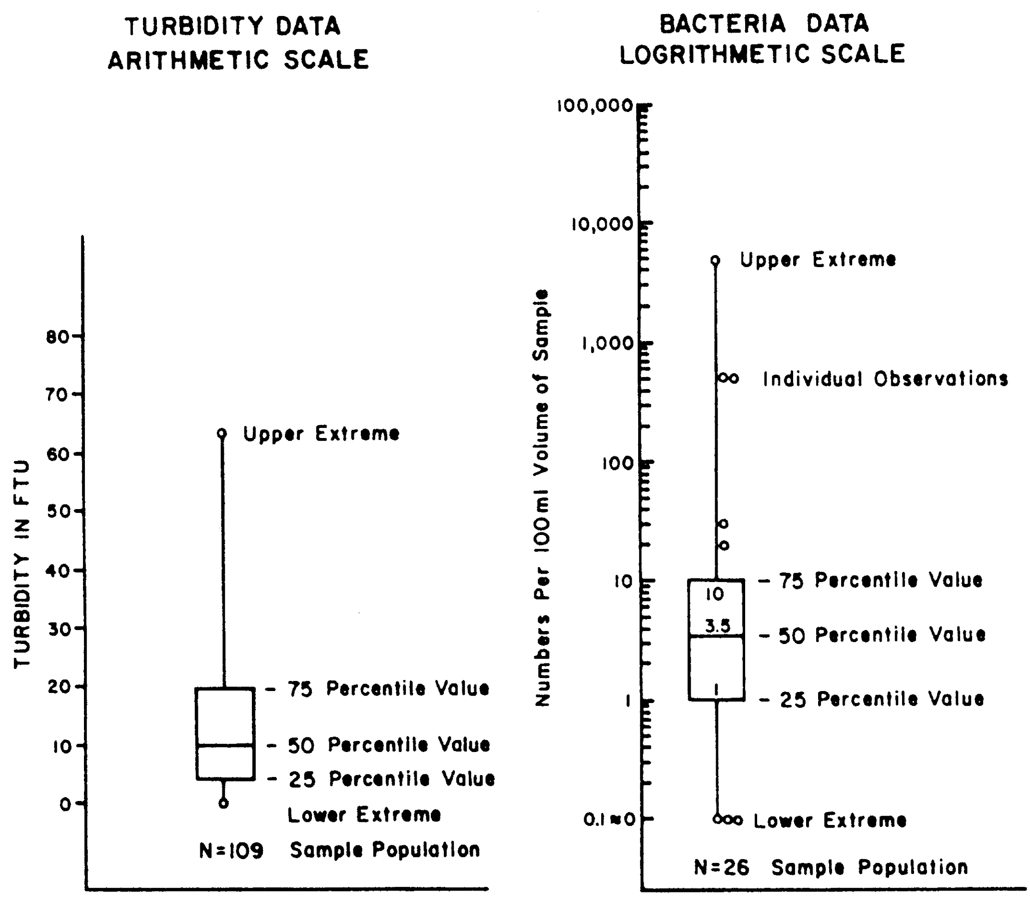


Figure 11. Example of Box and Whisker Pole Plots Showing Relative Distribution of Each Quartile of Data.

(McGill et al., 1978).

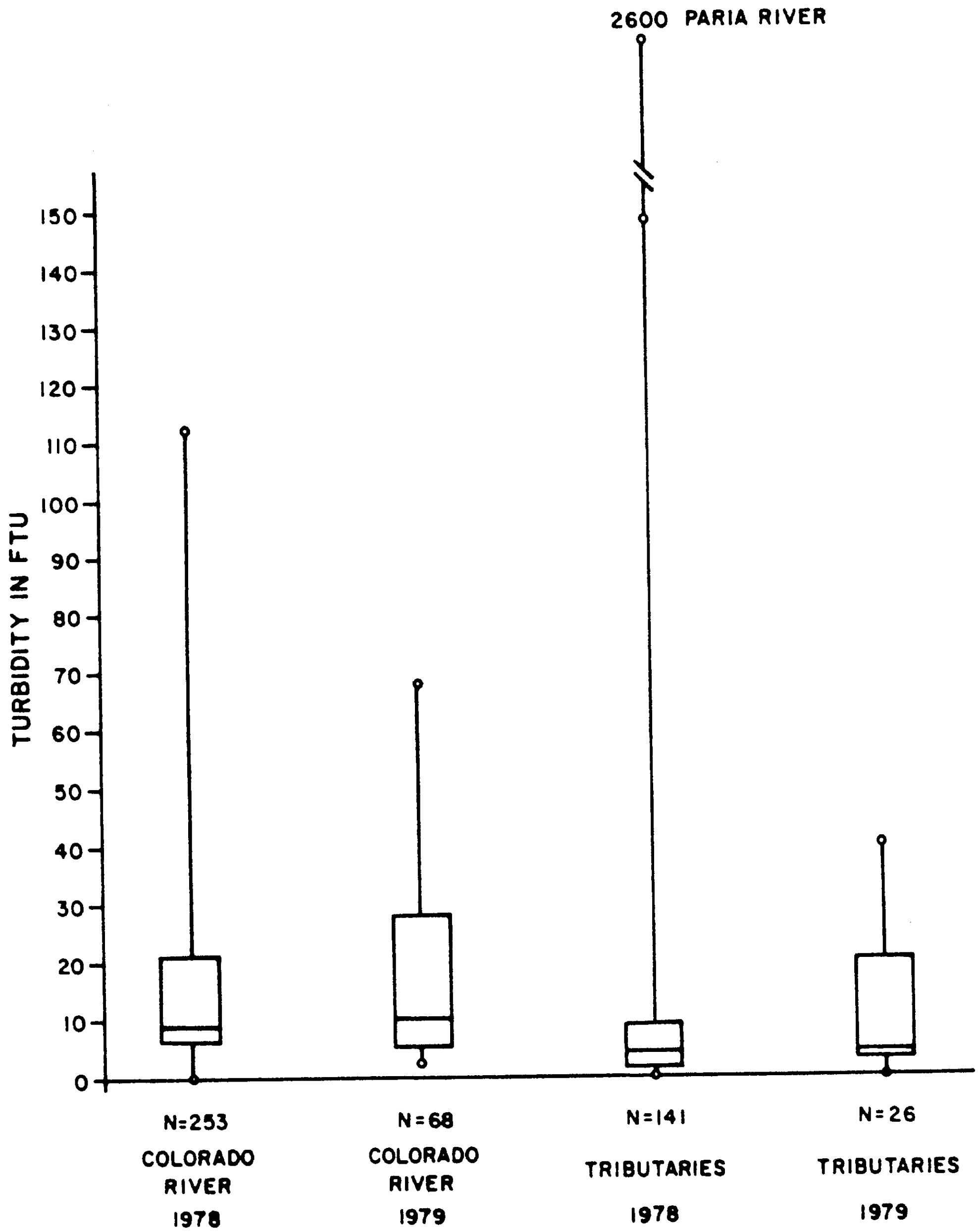


Figure 12. Surface Water Turbidities in Colorado River and Tributaries.

Table 16. Grand Canyon Colorado River 1978 Mean Chemical Concentrations.

Parameter Measured	Mean ($\overline{X}$)	Standard Deviation (s)	Sample Population (N)
Alkalinity (as mg/l $CaCO_3$)			
Phenolphthalein	15	30.5	31
Total	199	59.6	31
Hardness (as mg/l $CaCO_3$)			
Calcium	206	65.4	35
Total	365	108.3	35
Orthophosphate (as mg/l O-PO_4)	0.2	0.08	36
Nitrate (as mg/l NO_3)	1.2	0.83	35
Chloride (as mg/l Cl)	132	94.9	36
TDS (mg/l)	563	78.9	36
pH*	8.2		153

*Mean pH calculated as: $\overline{X} = -\log\left(\frac{\Sigma[H^+]}{N}\right)$

Orthophosphate and nitrate were monitored as indicators of organic loading of the aquatic system; orthophosphate and nitrate are often associated with domestic or agricultural pollution. Concentrations of these elements were relatively low, reflecting the isolation of the Grand Canyon from municipal and agricultural development.

2. Colorado River Tributaries

Chemical characteristics of 25 tributaries showed considerable variations between tributaries (Table 17) with each side creek reflecting the chemical composition of its watershed. The following discussion has been limited to unique characteristics of individual side creeks and has not been extended to all river tributaries.

a. Alkalinity, Hardness, and pH

Most of the Colorado River tributaries had a mean pH between 8.0 and 8.8 and had alkalinity values comparable to the river, from 150 to 250 mg/l of $CaCO_3$. Hardness in the tributaries was also generally equivalent to levels found in the river, except Monument Creek, Boucher Creek, Kanab Creek, Matkatameba, National Canyon, Fern Glen, Mohawk Creek and Pumpkin Spring which had relatively high total hardness. Stream flow in these tributaries at the time of sampling was less than 3 cfs or reduced to standing pools below seeps. Reduced flows, high evaporation potentials, and calcareous stream bed and watershed materials could have contributed to the high total hardness in these streams. Pumpkin Spring (mile 212) was unique in having precipitated a calcium carbonate bowl resembling a pumpkin. Alkalinity at Pumpkin Springs was also extremely high (1236 mg/l) and the pH of 6.8 was the only reading below 7.0 measured in the Canyon.

b. Orthophosphate and Nitrate-Nitrogen

Orthophosphate concentrations in side creeks were generally low, except in Shinumo Creek (mile 108) and Pumpkin Spring. Elevated levels in a single April, 1978 sample (Pumpkin Spring, 94.5 mg/l $O\text{-}PO_4$; Shinumo Creek, 6.5 mg/l $O\text{-}PO_4$) contributed to the high orthophosphate means for these tributaries. Phosphate in these tributaries was normally found elsewhere in the river corridor. Natural sources of orthophosphate could have concentrated in Shinumo Creek and Pumpkin Spring watersheds over the previous winter and appeared in the spring runoff sampled in the April sample or the samples may have been in error.

Nitrate nitrogen concentrations were low in most side creeks with Paria River, Havasu Creek, and Pumpkin Spring as exceptions. Again, single April observations contributed to inflating these means above

Table 17. Grand Canyon Tributary 1978 Mean Chemical Concentrations.

	Sample Population	Parameter Measured: Alkalinity (mg/l CaCO) Phenolphthalein		Alkalinity Total		Hardness (mg/l CaCO) Calcium		Hardness Total		Orthophosphate (mg/l O-PO)		Nitrate (mg/l NO)		Chloride (mg/l Cl)		TDS (mg/l)		pH
	N	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$**
Paria River	5	12	5.5	193	91.1	146	33.4	169	50.9	0.2	0.28	8.7	7.25	10.4	10.97	325	116.3	8.5
Vasey's Spring	6	8	9.0	162	65.3	130	77.1	206	68.9	0.3	0.19	2.9	3.72	2.9	2.84	220	196.9	8.7
Nankoweep Creek	6	23	13.4	220	100.2	121	59.7	325	39.4	0.2	0.12	2.1	3.16	1.7	0.70	338	12.9	8.6
Little Colorado	5	8	11.1	346	170.3	341	138.3	466	169.4	0.3	0.49	1.6	2.94	1960.0	587.07	283	80.9	8.0
Clear Creek	6	20	25.2	189	82.0	160	171.4	237	147.6	1.3	2.43	1.2	1.90	56.2	59.70	211	29.8	8.7
Bright Angel Creek	6	15	12.6	150	71.5	110	29.1	201	69.8	0.5	0.51	0.8	0.80	35.4	37.30	263	184.5	8.8
Garden Creek	6	47	91.6	177	65.4	86	68.8	190	29.5	1.3	2.78	1.2	1.56	51.5	68.61	196	23.2	8.5
Monument Creek	5	6	6.6	271	26.2	308	80.3	674	87.3	0.4	143.8	2.0	3.66	471.8	383.48	162	4.9	7.8
Hermit at River	6	8	8.9	212	91.4	160	61.9	299	39.2	0.2	0.36	3.0	5.24	152.8	17.15	526	71.2	8.4
Boucher Creek	6	9	10.4	177	71.1	218	56.3	536	126.6	0.2	0.18	2.4	3.41	570.8	269.44	122	18.1	8.3
Crystal Creek	6	17	9.2	186	65.5	127	69.2	247	35.7	0.1	0.08	1.6	2.08	144.2	54.98	538	158.3	8.5
Shinumo Creek	6	12	10.1	188	113.5	101	34.4	209	42.4	5.6	12.96	2.5	3.49	27.3	17.75	170	42.3	8.6
Upper Elves	6	10	3.9	148	59.2	158	66.0	377	84.3	0.8	1.00	2.6	3.20	55.3	22.10	482	24.8	8.5
Stone Creek	6	14	7.0	188	80.5	148	74.4	305	112.9	0.5	0.58	2.0	2.85	31.7	24.09	204	101.3	8.5
Tapeats Creek	5	9	8.8	195	37.4	103	24.5	160	39.2	0.2	0.06	0.9	1.20	29.6	32.6	160	23.5	8.6
Lower Deer Creek	6	13	9.3	179	75.4	120	29.6	171	47.6	0.9	1.70	1.7	2.25	26.8	31.97	185	20.3	8.7
Kanab Creek	6	14	16.1	122	46.6	378	51.2	676	104.1	0.1	0.07	2.3	3.41	40.8	29.44	777	47.6	8.3
Matkatameba	5	7	10.2	171	133.3	474	136.9	835	212.5	0.7	1.16	0.9	1.46	44.2	33.45	840	58.7	8.1
Middle Havasu	6	13	17.5	394	274.8	155	39.1	326	94.3	0.2	0.43	5.1	10.23	255.9	252.65	432	122.7	8.4
National Canyon*	5	1	1.8	264	360.3	521	368.2	4325	6537.6	1.6	3.32	3.4	5.46	139.2	140.75	1162	300.1	8.0
Fern Glen*	4	0	0	133	74.0	1040	30.0	1603	74.0	0.5	0.73	0.2	0.24	41.5	4.51	1125	407	7.6
Mohawk Creek*	5	5	9.1	131	64.6	746	337.9	1606	301.5	0.2	0.17	1.9	2.33	56.6	10.97	1357	226.9	8.2
Pumpkin Spring*	6	0	0	1236	1074.9	391	232.5	764	410.7	16.9	38.04	7.5	11.32	4867	3316	7708	5261.8	6.8
Three Springs	5	54	99.2	323	149.0	259	94.5	427	57.0	0.7	1.02	3.6	4.31	60.2	30.9	480	34.6	8.3
Diamond Creek	5	21	22.0	299	101.6	142	34.2	279	33.8	0.8	1.20	2.2	3.25	93.2	67.44	517	66.6	8.4

*Samples from standing pools below seeps; channel flow not observed in 1978.

**Mean pH calculated as: $\bar{x} = -\log\left(\frac{\Sigma[H^+]}{N}\right)$

levels found in other tributaries. Spring runoff flushing of the watersheds may have caused the increased nitrate concentrations observed.

Orthophosphate and nitrate levels in tributaries did not suggest excessive levels of organic decay usually associated with eutrophic aquatic systems.

c. Chloride and TDS

Most of the Colorado River tributaries with appreciable flow had TDS concentrations less than the river main stream. Tributaries represented only as pools had high TDS concentrations possibly produced by excessive evaporation. Chloride levels were also generally lower than in the river except for creeks with markedly reduced flows and the Little Colorado River and Havasu Creek. Little Colorado River water sampled by the 1978 research was primarily flow from springs known to be high in sodium chloride (NPS, 1979a). Havasu Creek had a substantially higher chloride concentration (620 mg/l) for one of six observations.

D. BACTERIAL WATER QUALITY DATA

Bacterial water quality data from the Colorado River corridor is presented in five units: 1) 1978 Colorado River data; 2) 1979 Colorado River data; 3) 1978 tributary data; 4) 1979 tributary data; and 5) 1979 stir sample data.

1. <u>1978 Colorado River Data</u>

Three bacterial parameters of the Colorado River were examined: a) FC densities in the river surface waters; b) FS densities in the river surface waters; and c) FC densities in river bottom sediments. Water quality standards for surface waters have been established utilizing coliform bacteria densities as indicator criteria of unacceptable water quality status (Table 18).

a. 1978 River Surface Water FC Densities

With some occasional exceptions, fecal coliform densities in the Colorado River surface water were predominantly low, infrequently exceeding 5 FC/100 ml (Figure 13). The distribution of FC bacteria along the length of the river was fairly uniform with the possible exception of the first 40 to 60 river miles where FC densities were consistently low. No associations between river FC concentrations and tributary inflows

Table 18. Water Quality Standards.

Water Use	Statistical Measure	Microbiological Criteria Coliforms/100 ml Total	Fecal	Turbidity
Potable Water[1]		When MF analysis is used: A. MCL* allowable is 1 total coliform as an arithmetic average of all samples per month. B. MCL allowable in one sample is 4 total coliform when ≤ 19 samples are collected per month, or MCL allowable in 5% of the samples when 20 ≥ samples are collected per month.		1 NTU[2] or 5 units if no interference with disinfection of microbiological analyses.
Recreation				
Full Body Contact	log $\overline{X}$/30 days		200[3]	50 NTU[4]
	Maximum in 10% of samples/ 30 days		400[3]	
Partial Body Contact	log $\overline{X}$/30 days		1000[3]	50 NTU[4]
	Maximum in 10% of samples/ 30 days		2000[3]	

*MCL refers to <u>maximum concentration level</u>.

[1]Public Law 93-523.

[2]National Interim Primary Drinking Water Regulations.

[3]Water Quality Criteria, FWPCA, April 1, 1968, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[4]State of Arizona Specific Standards for Protected Uses.

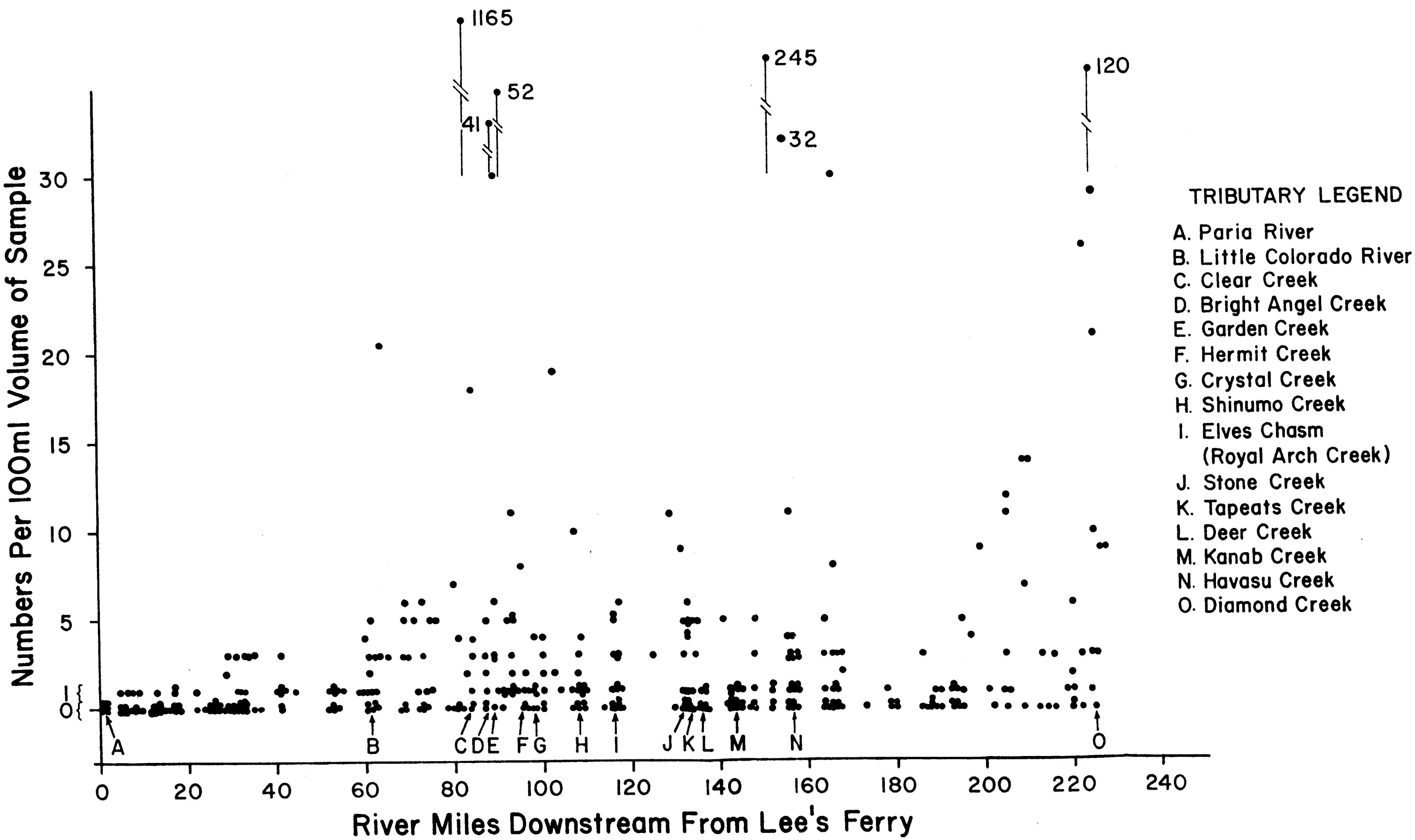


Figure 13. Fecal Coliform Distribution in the Colorado River, Grand Canyon, 1978.

Data points are individual observations collectively comprising a sample population of 424. Arrows indicate confluences of major tributaries.

were detected. Clusters of data points which appeared (Figure 13) represented repetitive sampling at fixed sites over the course of the research period and were not associated with the side creek confluences.

Variations in the distributions of FC bacteria in the Colorado River could have occurred during the course of the 1978 season, but were not apparent in the composite scattergram of the data (Figure 13). FC distributions per research trip show (Figure 14) no significant concentrations of bacteria associated with any particular river location during the research season.

Box and whisker pole plots offered an additional perspective of the FC distributions in the river and a means of comparing fixed site and time series findings (Figure 15). Low FC densities predominated in the river surface water; a combined data distribution showing an FC density of 3 FC/100 ml or less in 75% of the 424 river samples taken indicated high quality recreational contact surface waters. Drinking water quality was not suggested as FC bacteria did occur in varying densities in 75% of the samples taken. FC distributions detected by the time series and fixed site sampling designs were highly similar; both sampling approaches indicate the same water quality status. Turbid storm runoff from tributaries did not occur during the research period; fixed site bracketing would be required to detect influences of turbid side creek inflows.

b. 1978 River Surface Water FS Densities

Densities of FS bacteria in Colorado River surface waters were measured during five of six 1978 research trips (Figures 16 and 17). Relative to FC densities, FS densities were considerably higher. Ratios between FC and FS densities have been used to indicate probable sources of contamination (EPA, 1978); FC/FS ratios of greater than 4:1 are indicative of human waste contamination and ratios less than 0.7 are suggestive of nonhuman sources, primarily warm-blooded animals. Based on paired FC and FS samples, with minimum FS densities of 100 FS/100 ml (Geldreich, 1976), a mean FC/FS ratio of 0.10 was calculated for the Colorado River surface waters, indicating animal waste as the most abundant source of fecal contamination.

c. 1978 River Bottom Sediment FC Densities

Bottom sediment FC densities in 1978 were strikingly higher than surface water densities, but, as surface water FC distributions, showed no association with location along the river channel (Figure 18). FC densities in the sediments did increase through the river running season (Figure 19). Surface water FC densities did not show similar increases (Figure 14), suggesting a cumulative concentration effect of FC bacteria in bottom sediments. FC densities in Colorado River bottom sediments for the entire 1978 research period have been collectively illustrated in Figure 20.

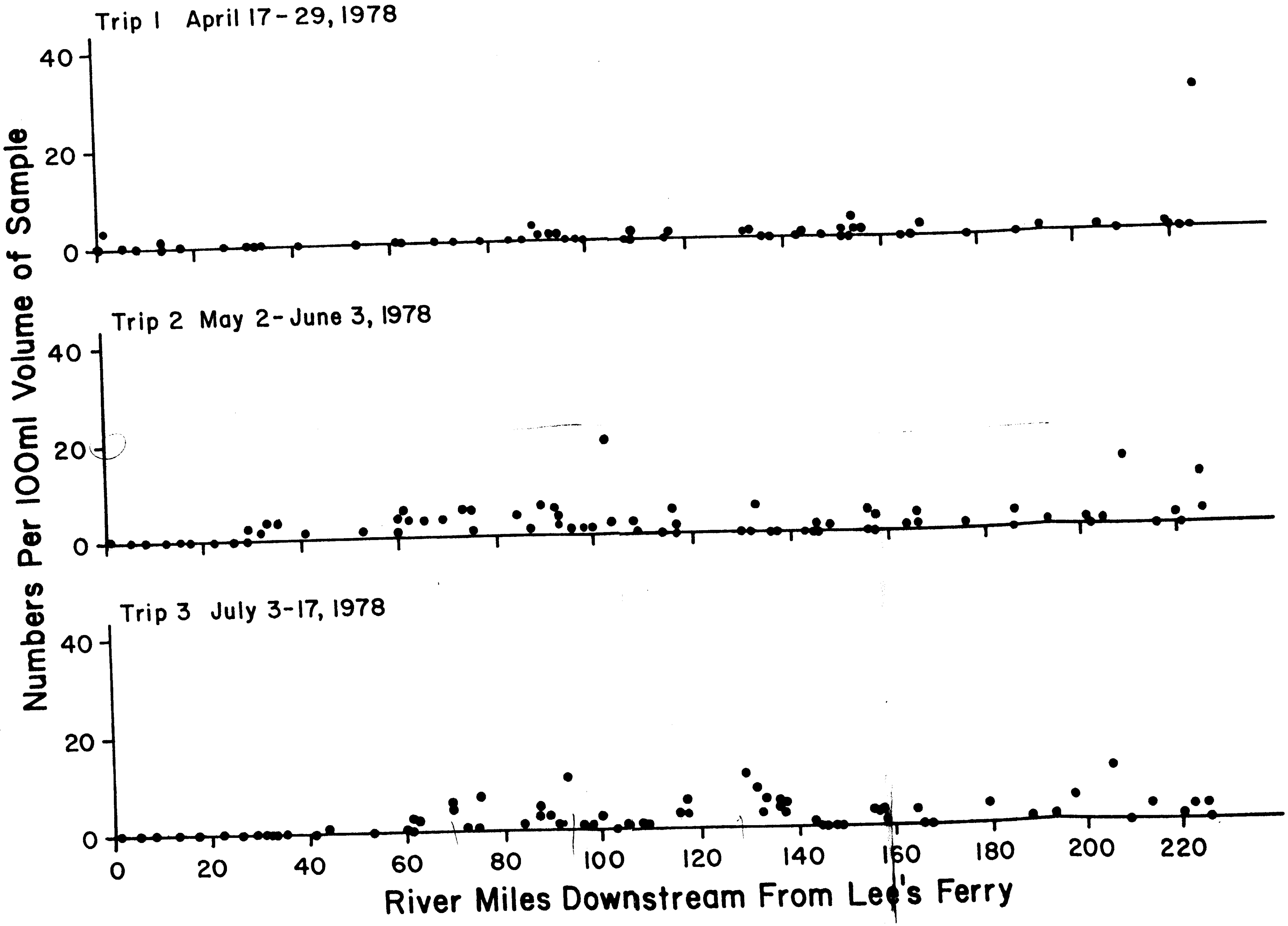


Figure 14. Fecal Coliform Distribution in the Colorado River, Grand Canyon, per 1978 Research Trip. Data points are individual sample observations. (Figure continued next page.)

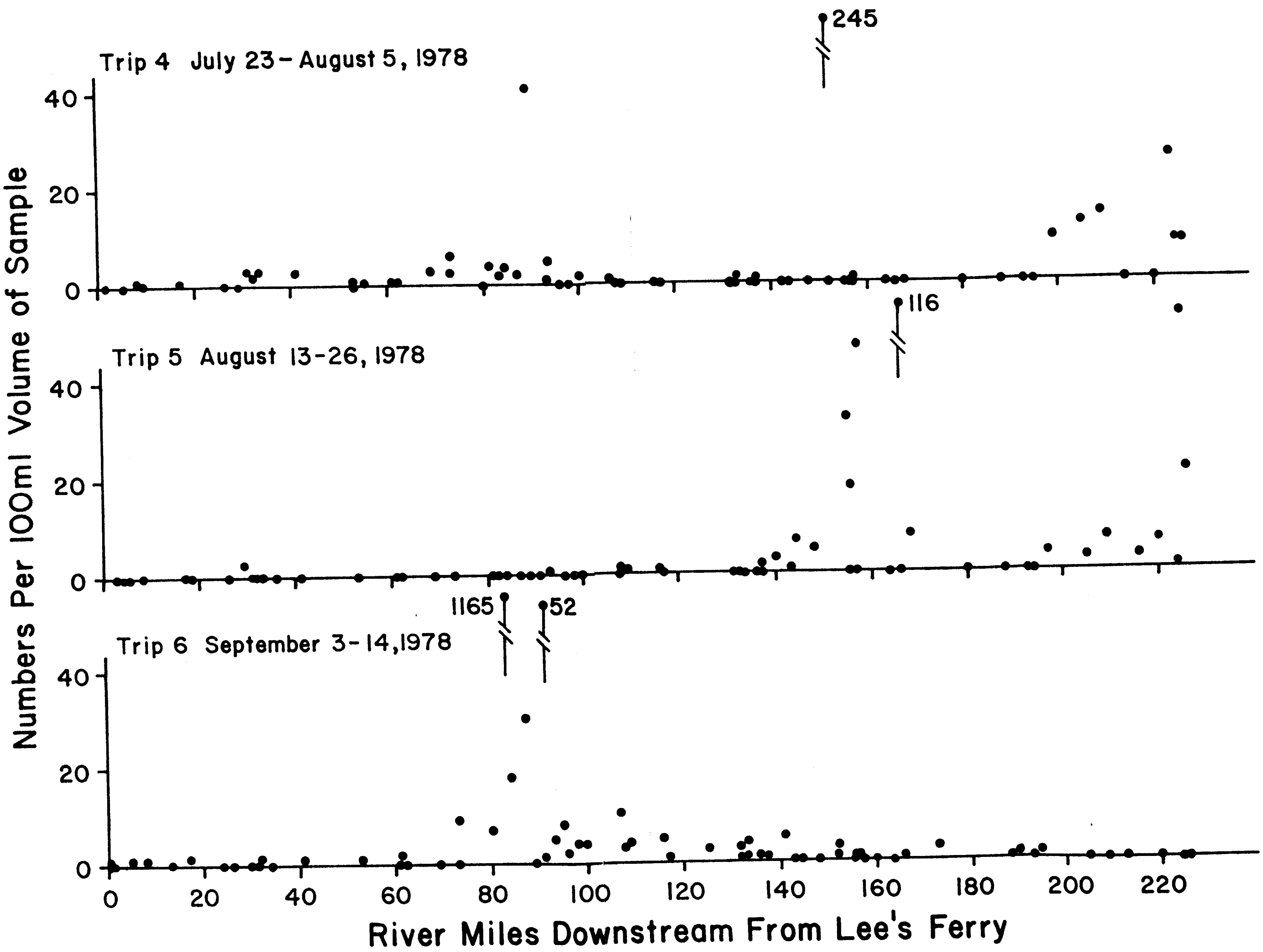


Figure 14.--continued.

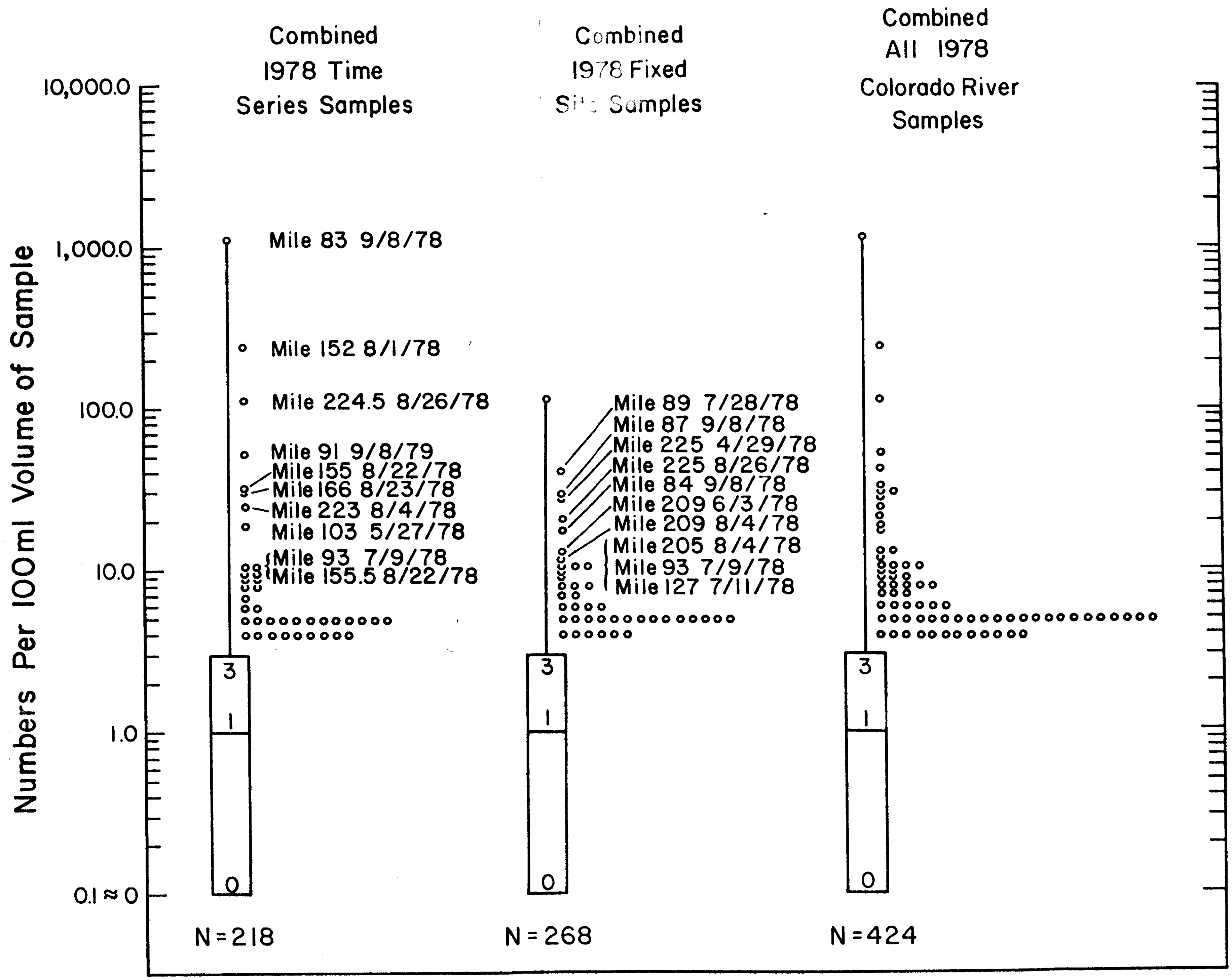


Figure 15. Box and Whisker Pole Representations of 1978 FC Distributions in the Colorado River, Grand Canyon.

Combined river samples represent summation of nonoverlapping time series and fixed site sample populations. During 1978 research, the lower extreme FC density value (0) and the 25 percentile values were equivalent. Nonoverlapping individual upper 25 percentile values are identified by circles and, for FD densities > 10 FC/100 ml, by river mile and observation date. Note logrithmetic scale.

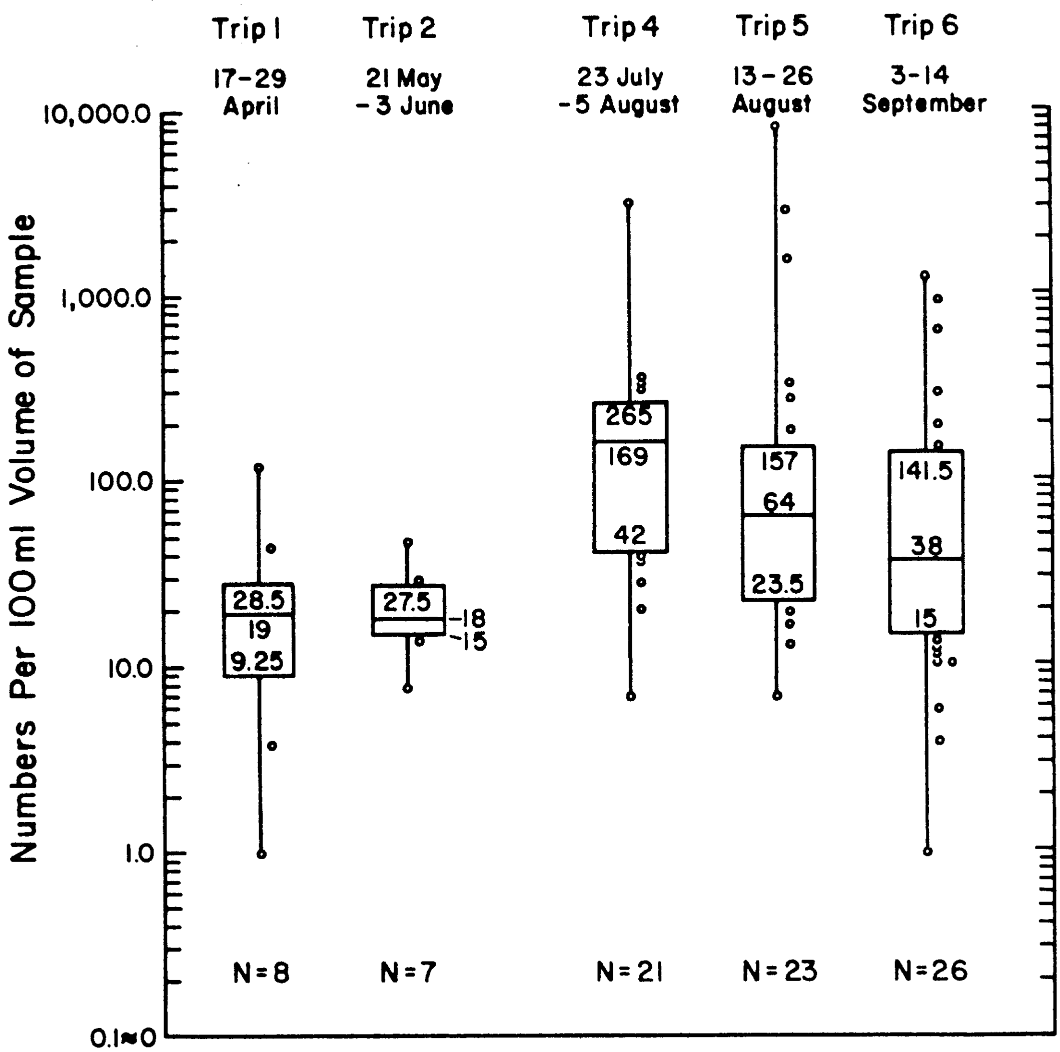


Figure 16. Distributions of FS Bacteria in Colorado River Surface Waters Measured on Five Research Trips in 1978.

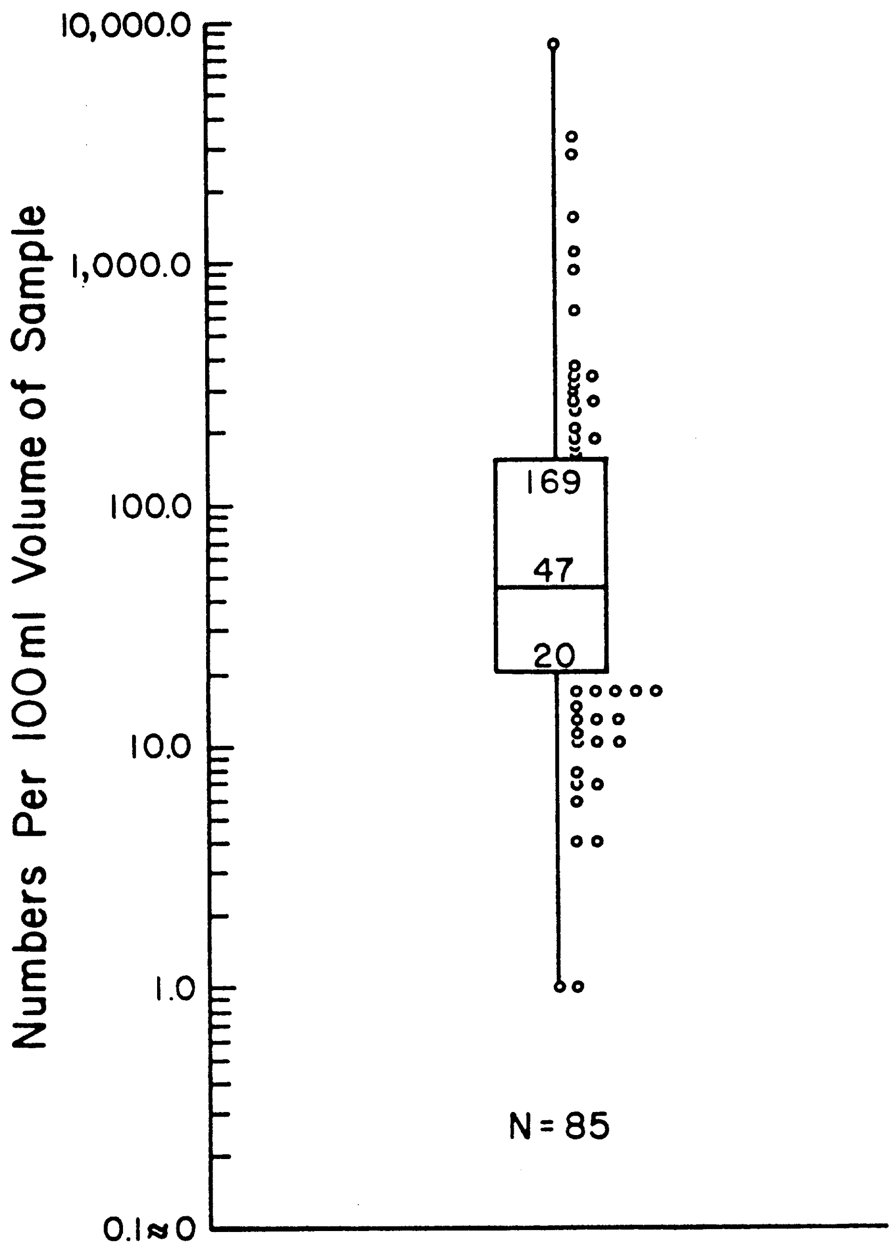


Figure 17. Composite 1978 Distribution of FS Densities in Colorado River Surface Waters.

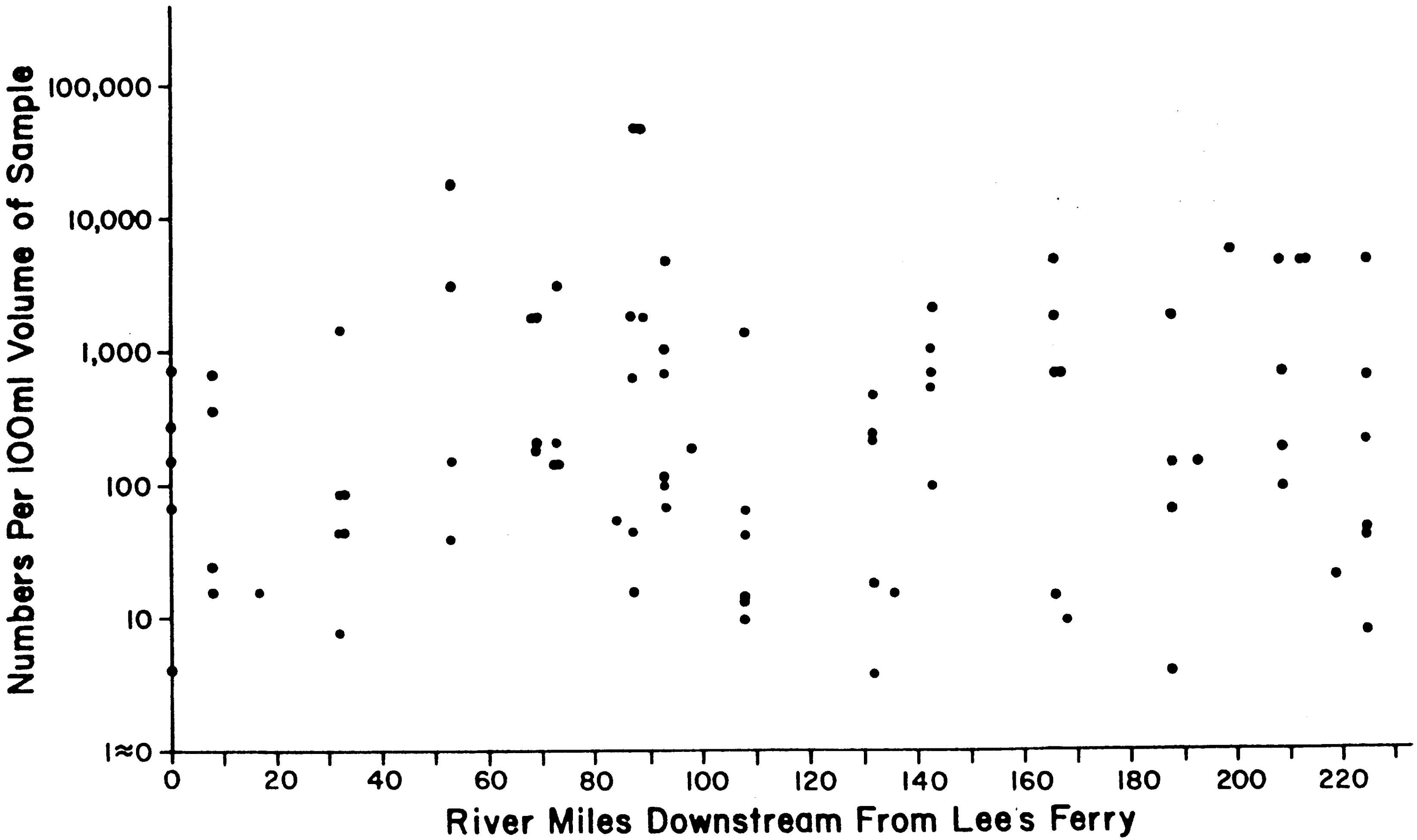


Figure 18. 1978 FC Distribution in Bottom Sediments of the Colorado River, Grand Canyon.

Sample population = 83.

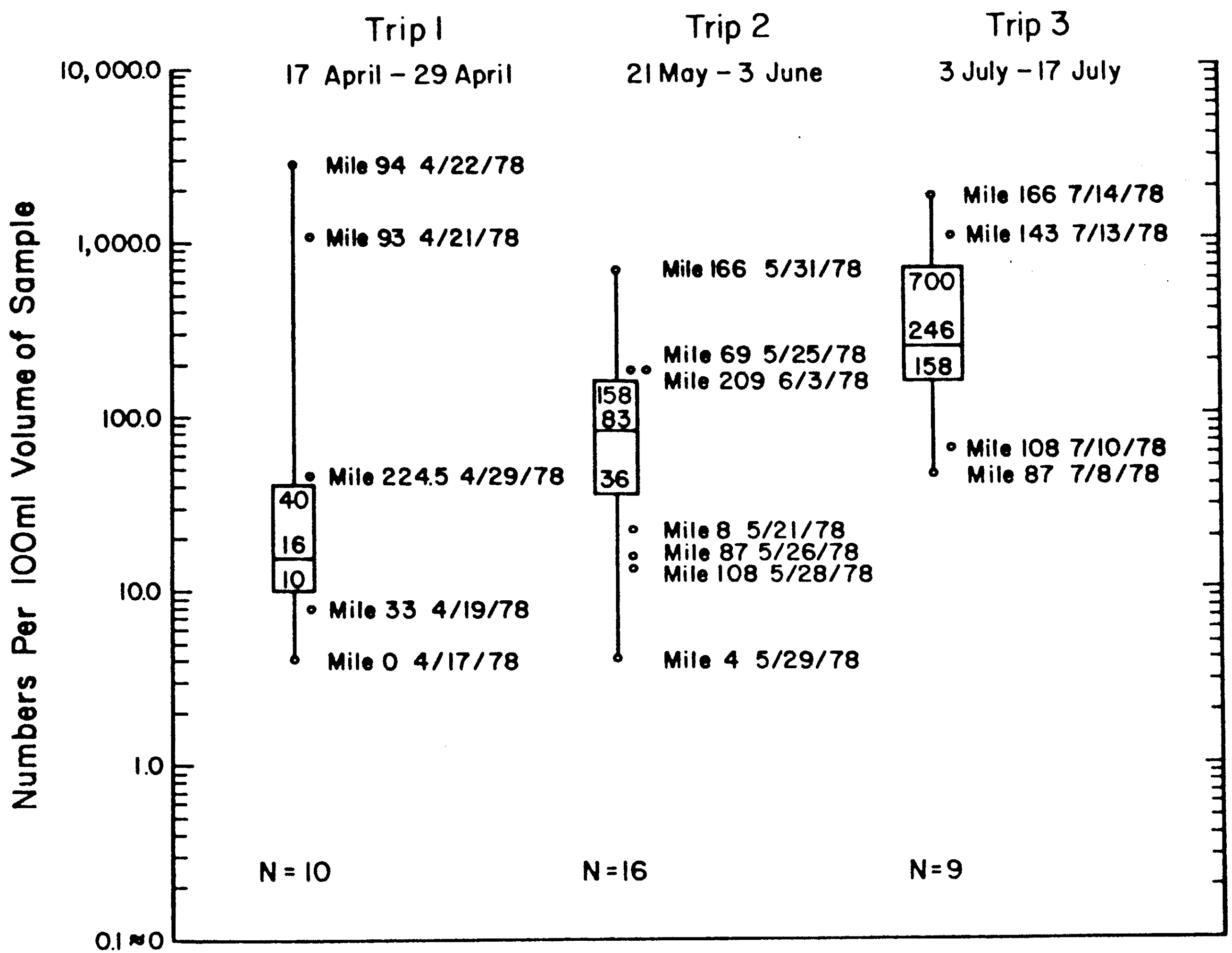


Figure 19. FC Densities in Colorado River Bottom Sediments on Each 1978 Research Trip.

(Figure continued next page.)

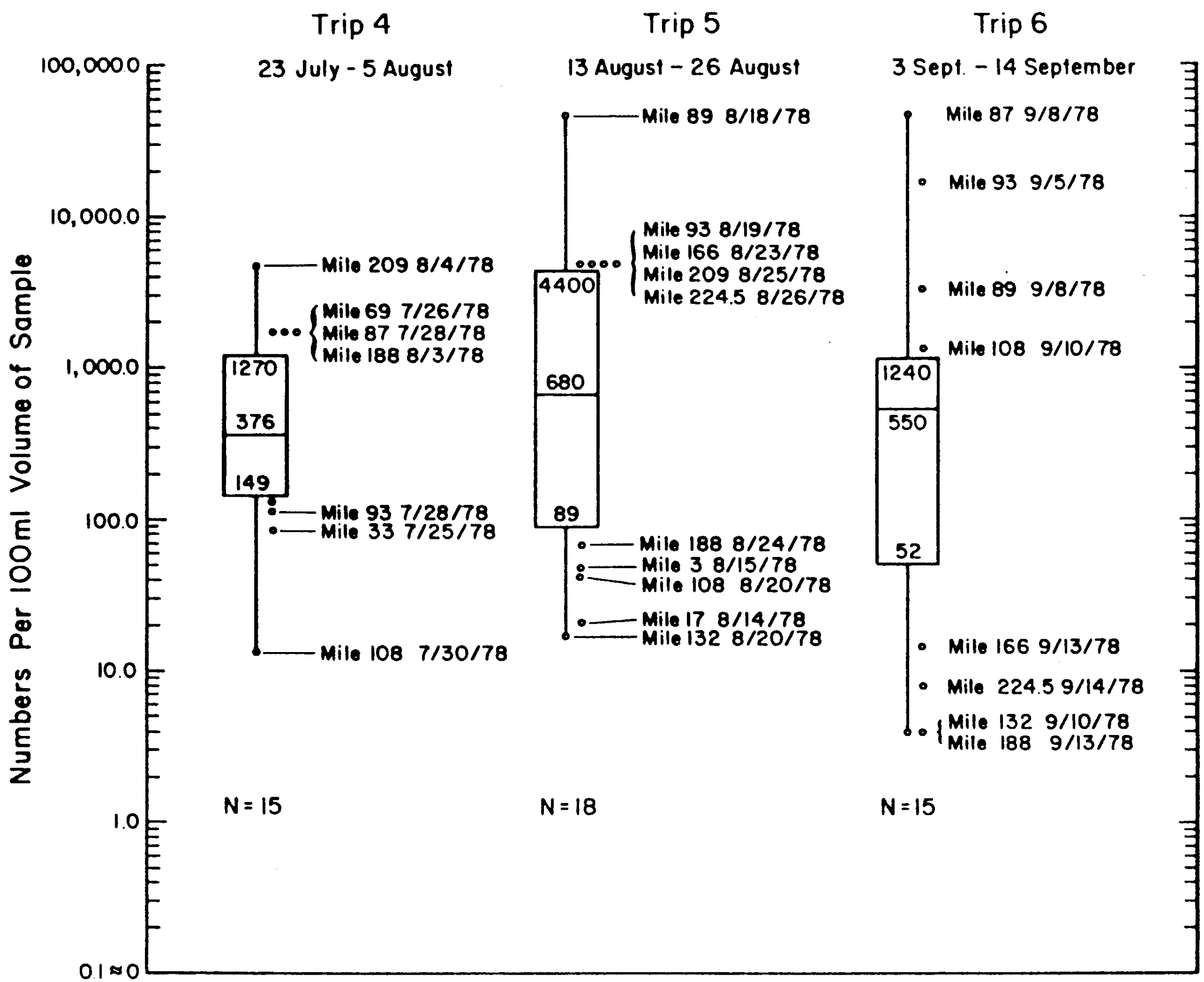


Figure 19.--continued.

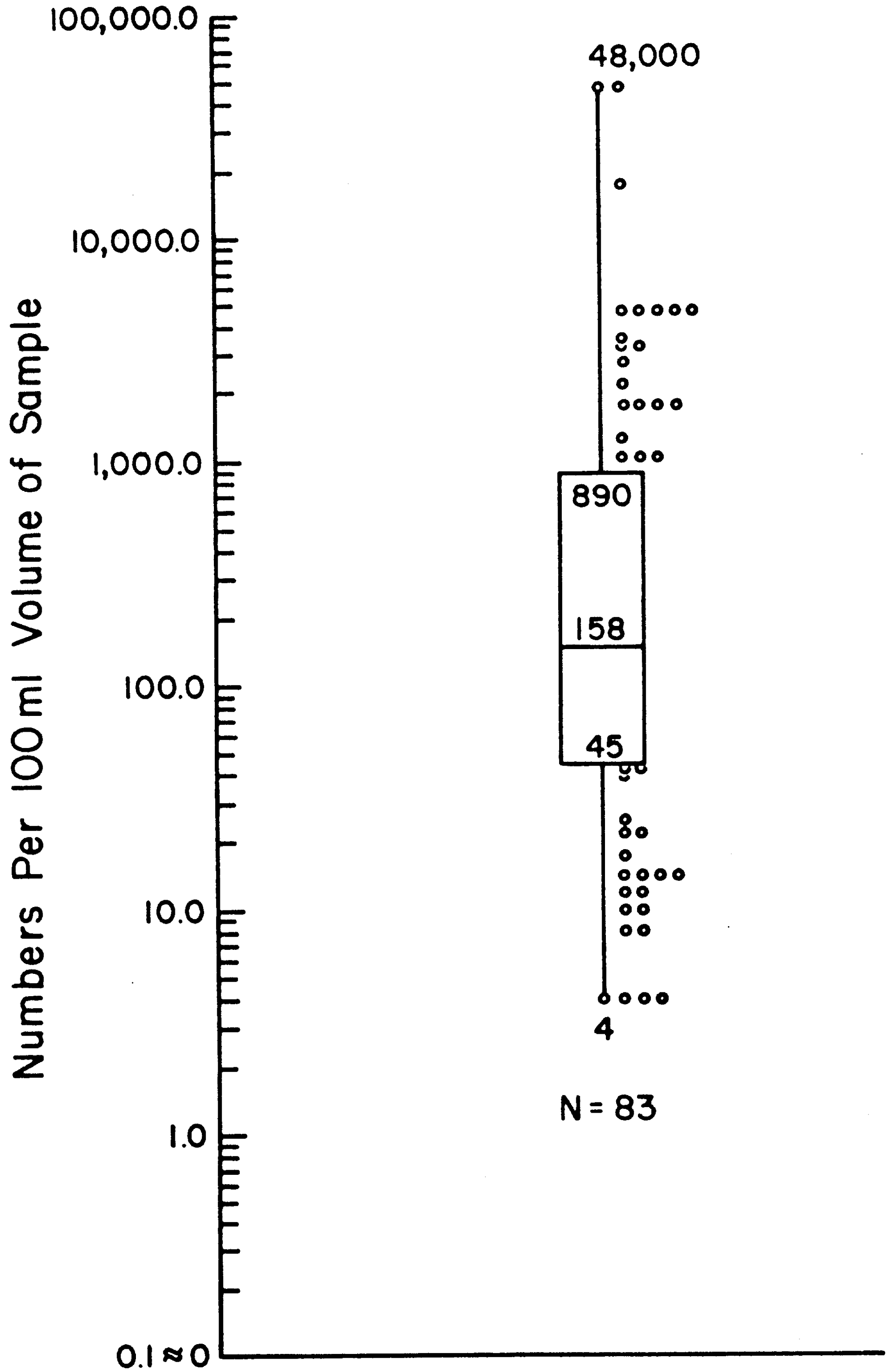


Figure 20. Composite 1978 Distribution of FC Densities in the Colorado River Bottom Sediments, Six Research Trips Included.

2. 1979 Colorado River Data

Water quality analyses of the Colorado River in 1979 (July and August) found FC distributions similar to those reported for 1978. Contamination levels in surface waters were again predominantly low; bottom sediments harbored significantly higher densities of FC bacteria (Figure 21). As in 1978, no associations were found between river surface water quality and tributary inflows.

Relatively high surface water FC counts (48 FC/100 ml) were found at Lees Ferry on 20 July 1979; previous research trips, 1978 and 1979, had reported a maximum FC density of 2 FC/100 ml at that site. Bottom sediment FC densities at Lees Ferry were also relatively high compared to 1978 findings; FC densities of 6000 FC/100 ml and 2750 FC/100 ml were detected in 1979.

These data are of particular importance because Lees Ferry's geographical position on the Grand Canyon upper watershed is approximately 16 miles below Glen Canyon Dam and above the confluence of any major tributaries. Evidently, sufficient fecal input exists, at times, in this relatively short stretch of canyon to create fairly significant concentrations of bacteria at Lees Ferry.

3. 1978 Tributary Data

Distributions of indicator bacteria in tributaries during 1978 resembled those found in the Colorado River (Figure 22); tributary surface water FC densities were generally low, 7 FC/100 ml or less in 75% of the 1978 samples, and FC densities in bottom sediments were relatively high. Surface water FS densities were also high relative to surface water FC densities; a mean 1978 FC/FS ratio of 0.06 represented the tributaries collectively. Bottom sediments were apparently functioning as a holding and concentrating medium for enteric bacteria while surface waters maintained predominantly low contamination levels. Warm-blooded animal fecal waste was indicated as the most probable source of contamination.

4. 1979 Tributary Data

As in 1978, the marked dichotomy between tributary surface water FC densities and those in the bottom sediments was readily apparent in 1979 (Figure 23). The upper Elves Chasm sample of 5 August 1979 was of particular interest as the surface water FC density of 4810 FC/100 ml (previous high of 120 FC/100 ml recorded 8/20/78) was approaching a high level relative to the bottom sediment FC density (9200 FC/100 ml). Present at the time of sampling were more than 50 river runners engaged in

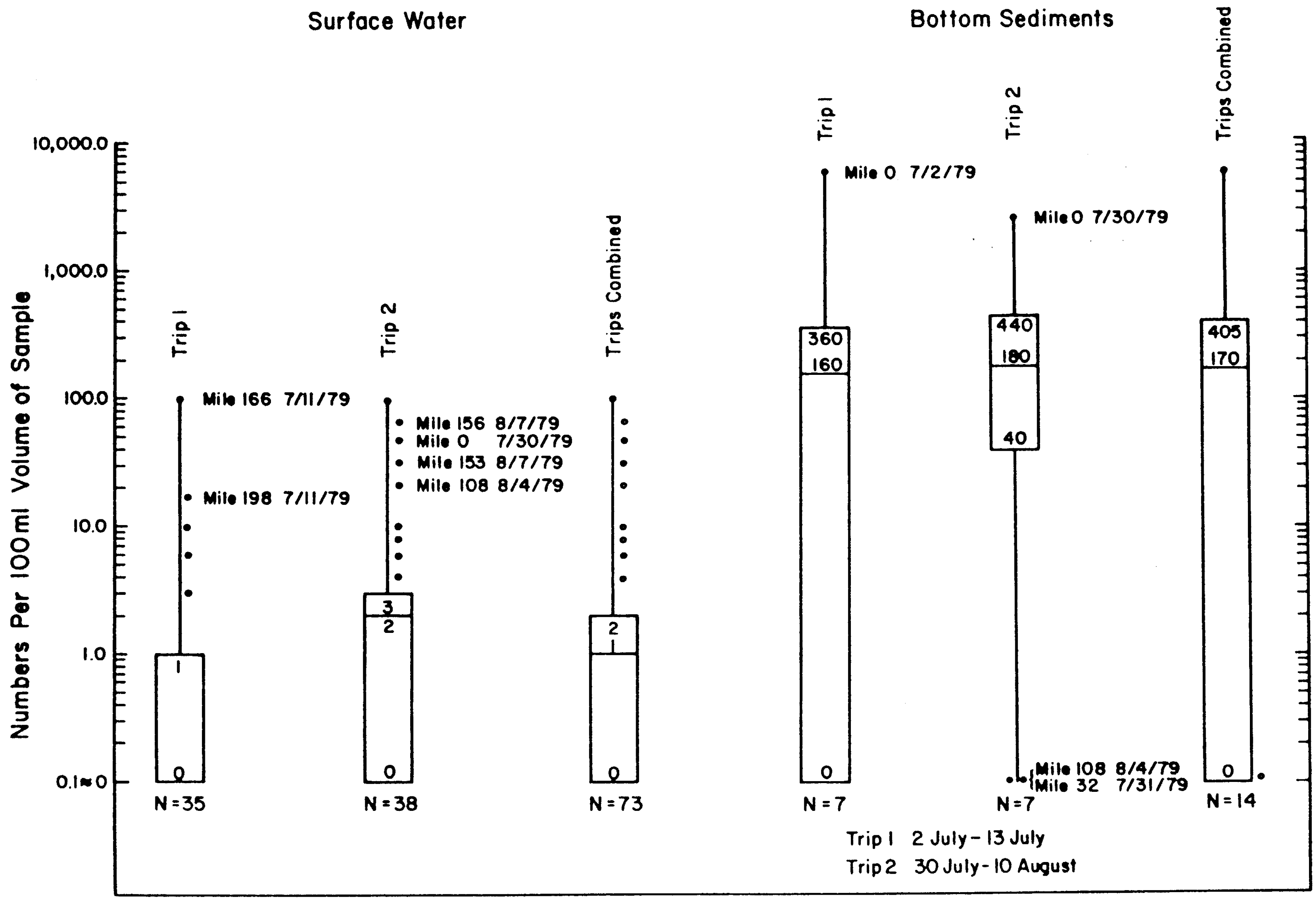


Figure 21. 1979 FC Distributions in Colorado River Surface Waters and Bottom Sediments.

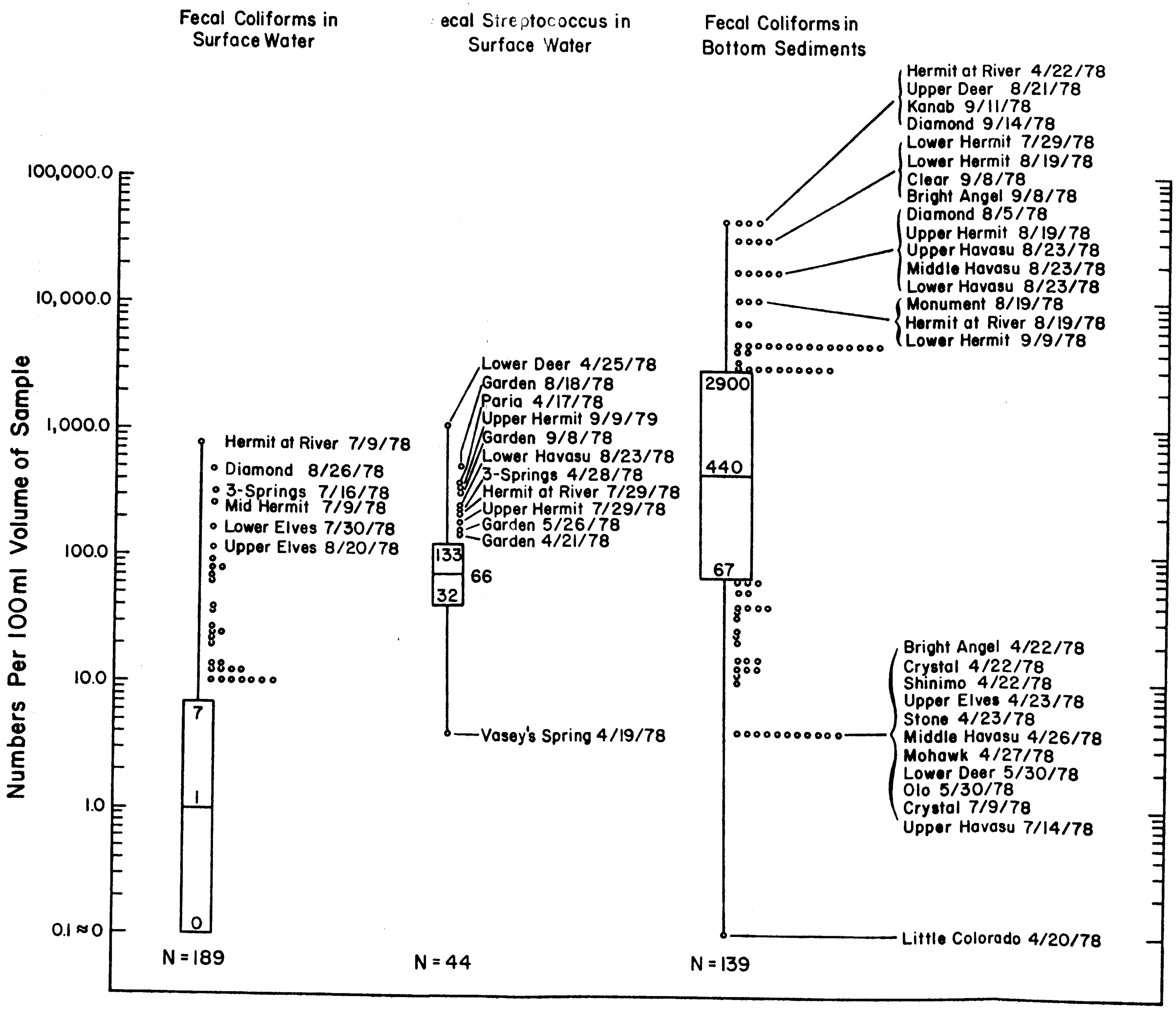


Figure 22. 1978 Distributions of FC Bacteria in Grand Canyon Tributary Surface Water and Bottom Sediments and of FS Bacteria in Tributary Surface Water, Twenty-Six Tributaries Represented.

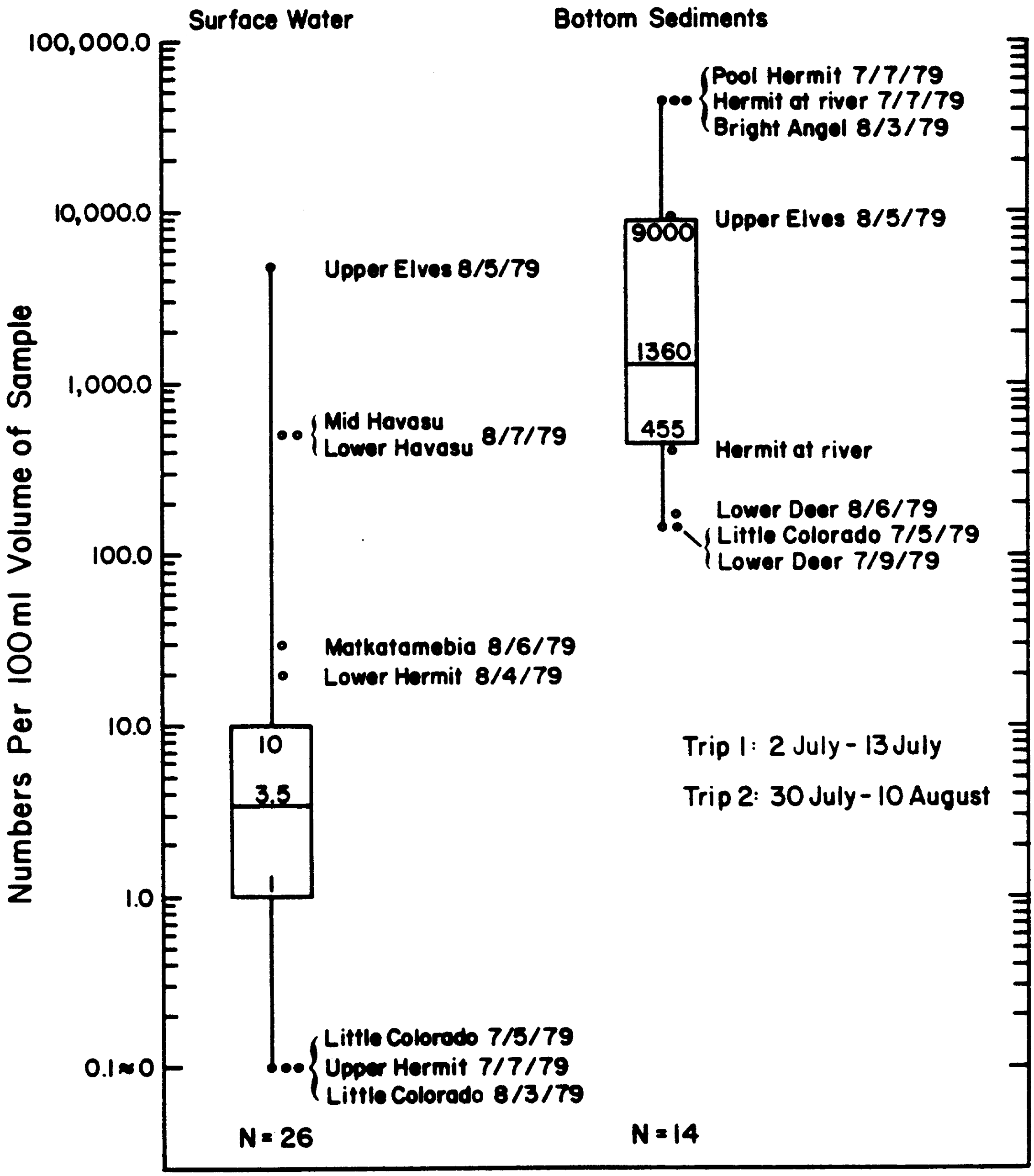


Figure 23. 1979 FC Distributions in Surface Waters and Bottom Sediments of Eleven Grand Canyon Tributaries.

various water play activities which resulted in considerable disruption of the bottom sediments, a strong indication of the impact bottom sediments can have on surface water quality.

Multiple sample sites of Havasu and Hermit Creeks in 1978 and 1979 provided a basis for detailed water quality examinations (Figures 24 and 25). Havasu Creek (Figure 24), among the tributaries most intensively used by river runners, received intensive use from backpackers visiting the Havasupai Indian Reservation and drained the population center of the reservation. Hermit Creek (Figure 25) was intensively used by backpackers from the South Rim of Grand Canyon (Table 3, Section II.A).

Both Havasu and Hermit Creeks showed predominantly low surface water FC densities and high bottom sediment FC densities. Water quality analyses of these creeks also showed that while most of the samples measured FC densities within a narrow range, a wide variety of FC concentrations did exist.

5. 1979 Stir Sample Data

Stir sample FC data for the Colorado River and tributaries are shown in Table 19 along with the appropriate surface and bottom sediment FC data. In most cases, stir sample FC densities represented a relative increase in contamination over the ambient surface water FC densities, demonstrating the potential impact of resuspended bottom sediment material on surface water quality.

E. STATISTICAL RESULTS

Statistical examinations were made of two water quality situations: 1) fecal coliform distributions along the length of the Colorado River and 2) the relationships between fecal coliform densities in surface waters and bottom sediments.

1. Fecal Coliform Distributions in the Colorado River

Fecal coliform bacteria appeared to be fairly uniformly distributed through the length of the Colorado River with the possible exception of the first 40 to 60 miles of river below Lees Ferry where FC densities appeared to be consistently lower than downstream reaches of the river (Figure 13, Section IV.D.1.a).

Examination of the distribution of FC bacteria along the length of the Colorado River required grouping of the 424 river suface water samples from 1978 by sample site location; 23 locations were designated, each representing a sequential 10 mile segment of the 225-mile river

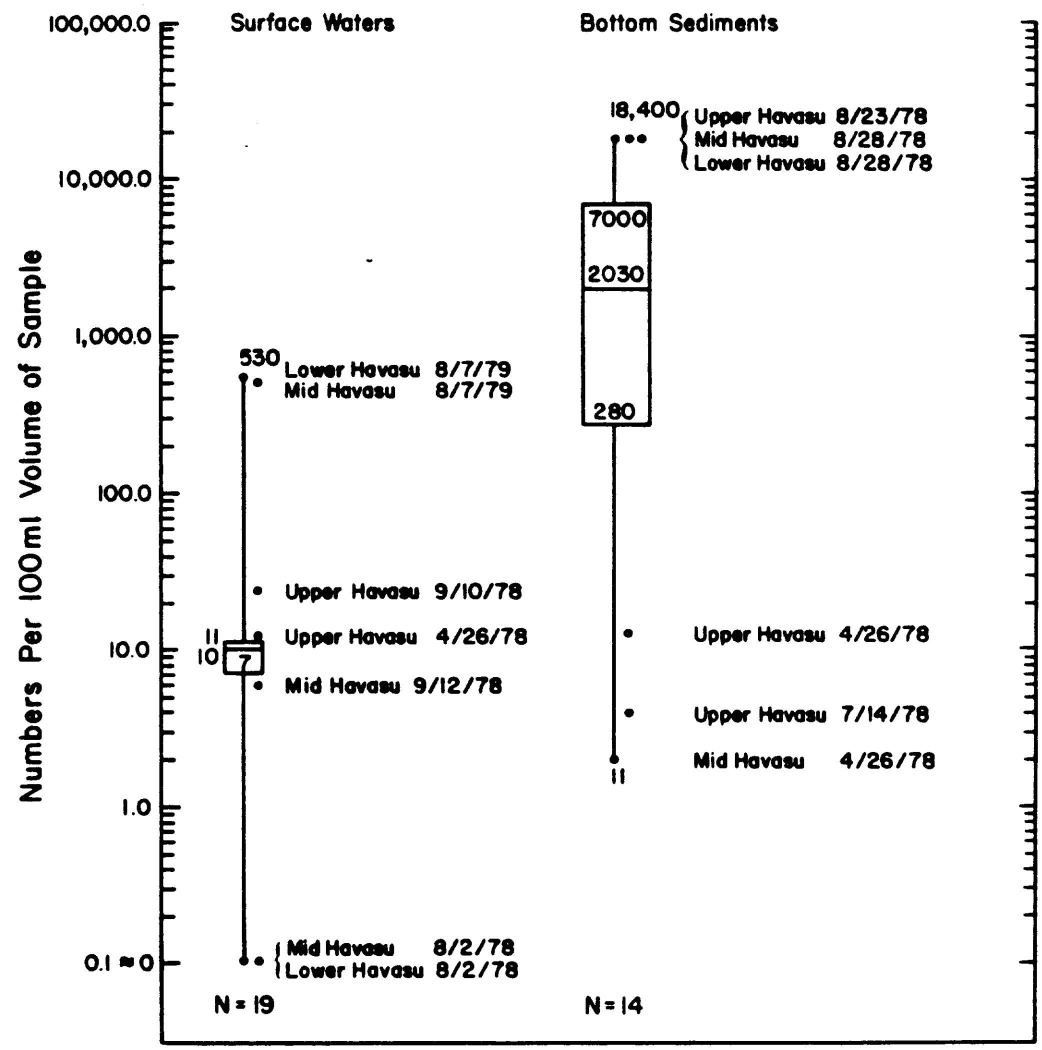


Figure 24. Surface Water and Bottom Sediment FC Distributions in Havasu Creek during 1978 and 1979, Collectively.

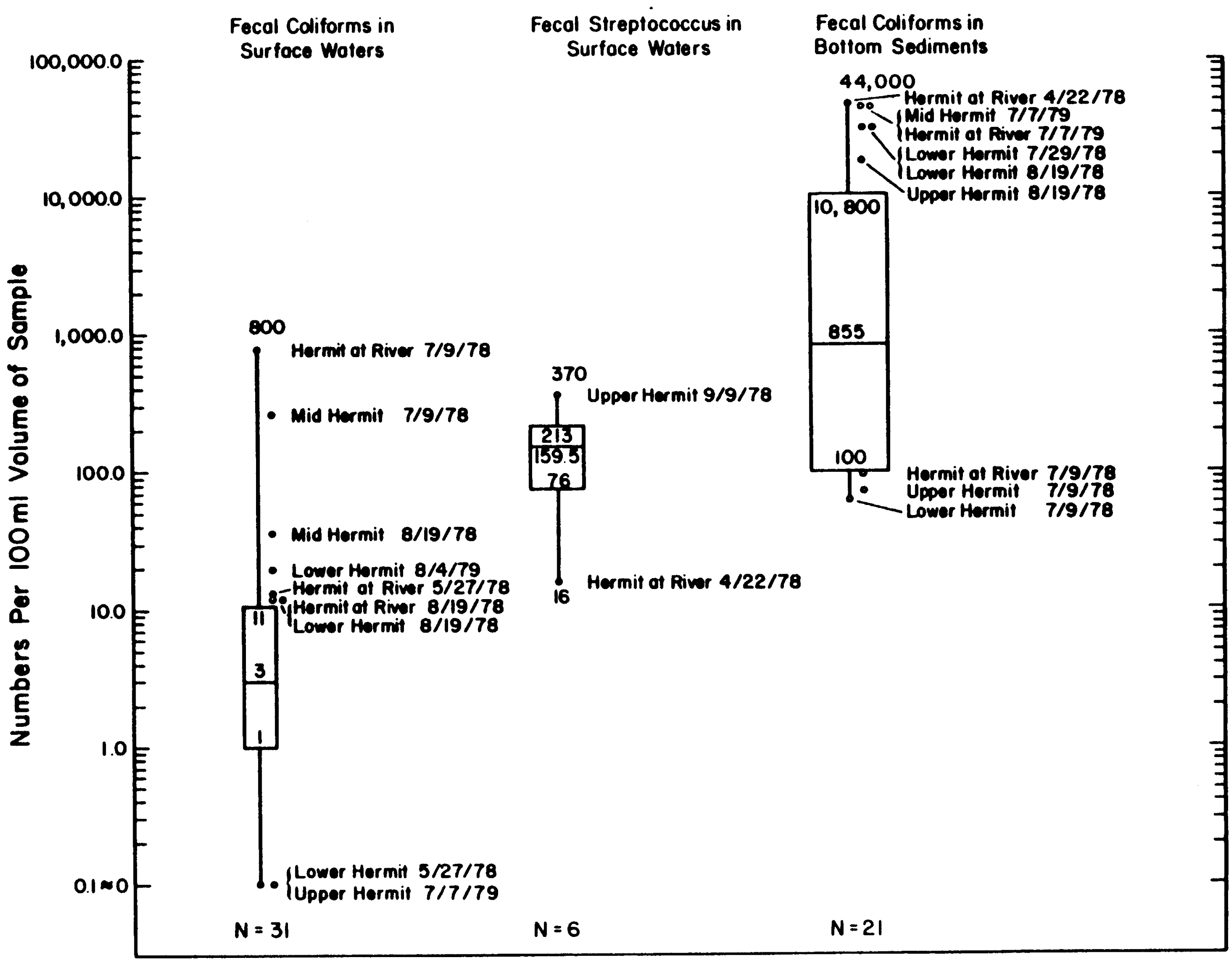


Figure 25. Surface Water and Bottom Sediment FC Distributions and Surface Water FS Distributions in Hermit Creek during 1978 and 1979, Collectively.

Table 19. Results of 1979 Grand Canyon Stir Samples.

Site	Date	Fecal Coliform Densities in Numbers/100 ml of Sample		
		Surface Water[1]	Stir[2]	Bottom Sediment[2]
Tributaries				
Little Colorador River	7/5/79	0	1	160
Middle Hermit	7/7/79	4	70	44,000
Elves Chasm	7/8/79	8	60	8,400
Lower Deer Creek	7/9/79	2	0	160
Middle Havasu	7/10/79	9	0	600
Little Colorado River	8/3/79	0	130	860
Middle Hermit	8/4/79	3	70	560
Elves Chasm	8/5/79	4810	4600	9,200
Lower Deer Creek	8/6/79	2	0	180
Middle Havasu	8/7/79	510	1500	1,860
River				
Lees Ferry Mile 0	7/2/79	2	0	6,000
Unkar Mile 72	7/5/79	0	0	0
Above Bright Angel Mile 87	7/6/79	4	0	360
Above Shinumo Mile 108	7/8/79	1	0	360
Below Stone Mile 132	7/9/79	0	0	0
National Camp Mile 166	7/11/79	100	70	160
Lees Ferry Mile 0	7/30/79	48	0	2,720
Unkar Mile 72	8/3/79	3	230	420
Above Bright Angel Mile 87	8/3/79	0	0	180
Below Stone Mile 132	8/5/79	0	90	80
National Camp Mile 166	8/7/79	10	70	460

[1]FC density measured by MF which yields precise number.

[2]FC density measured by MPN which yields mean index of probability distribution; reported density could be higher or lower. MPN and MF must be compared on a relative basis.

course in Grand Canyon. Log mean FC densities for each river segment were calculated from respective surface water samples representing the segment. A least significant difference test (LSD), at the 0.05 significance level, examined the 23 segment means for homogeneity (Figure 26).

Extensive overlap between the subsets indicated that surface water quality status was similar throughout most of the 225-mile length of the river. River miles 0 to 40 were represented only in subset 1; FC densities in this river segment tested significantly lower than some downstream areas. In terms of recreational contact water quality, these differences have no significant implications for river runners as the entire river length was of high recreation contact quality.

2. Fecal Coliform Densities in Surface Waters and Bottom Sediments

Box and whisker pole plots show striking differences in surface water and bottom sediment FC densities in both the Colorado River and tributaries. The relative relationship between FC densities in surface waters and bottom sediments are further examined by statistical means. Log mean FC densities in surface waters and bottom sediments for each research trip (Figure 27) show the relative relationship between these environments and a 1978 trend first shown in Figure 19 (Section IV.D.1.c); bottom sediment FC densities are increasing through the river running season in the Colorado River and tributaries. Data for 1979 are not extensive enough to confirm or deny the apparent 1978 trend.

An LSD examination of the trip log mean FC densities in river bottom sediments shows three statistically distinct concentration levels of the bacteria which increase in order through the river running season (Figure 28). Correspondingly, two statistically distinct concentration levels of FC bacteria in river surface water show no relationship to time (Figure 28). LSD analysis of tributary bottom sediment and surface water FC densities show similar characteristics (Figure 29); bottom sediment FC densities increase dramatically through the research season and surface water FC densities show no significant concentrations or trends.

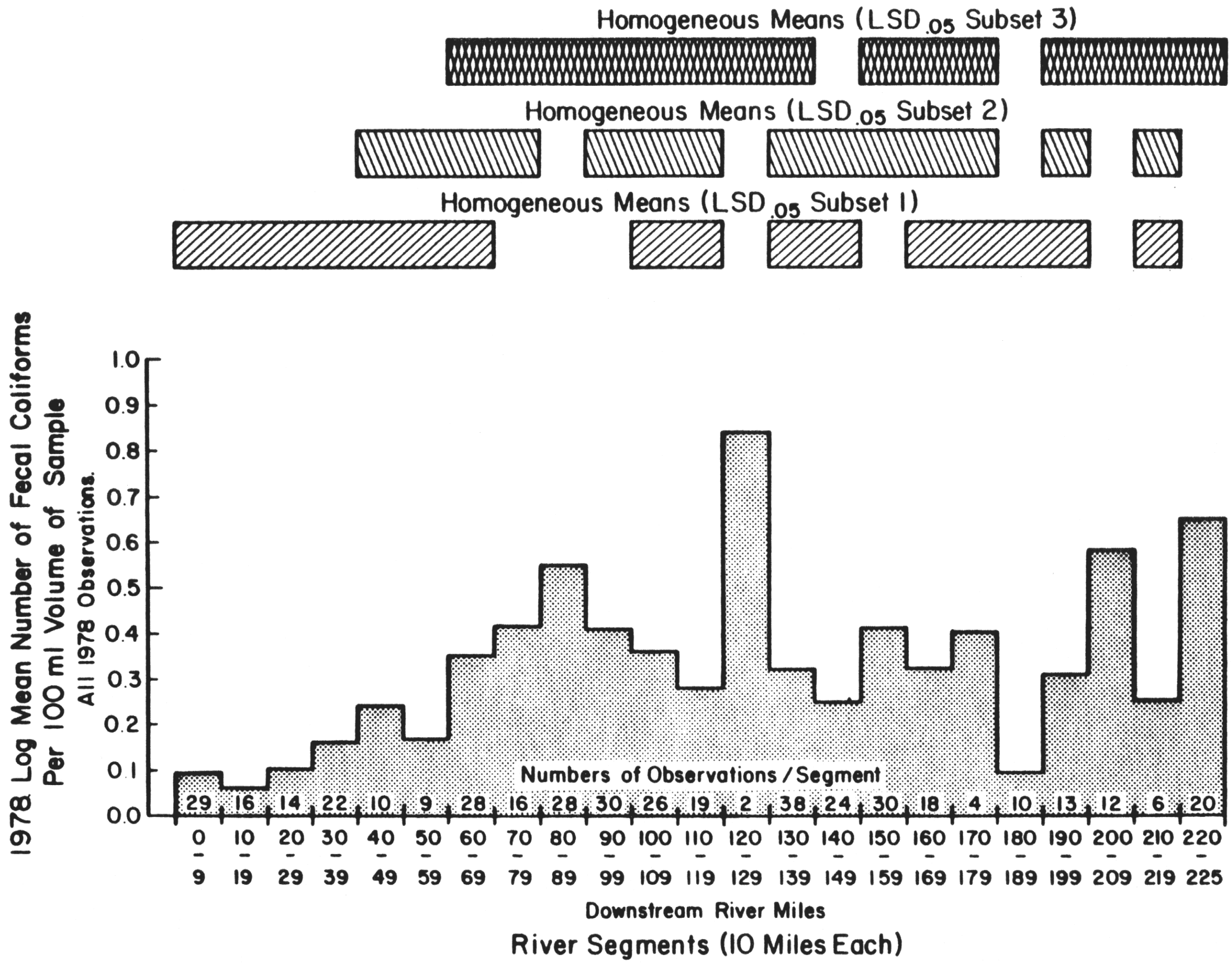


Figure 26. Least Significant Difference Test of River Segment Log Mean FC Densities.

River segments are 10 miles long; numbers of observations per segment log mean are equal to the number of 1978 surface water samples per corresponding river segment. $LDS_{.05}$ subsets represent groups of homogeneous means with increasing mean FC densities.

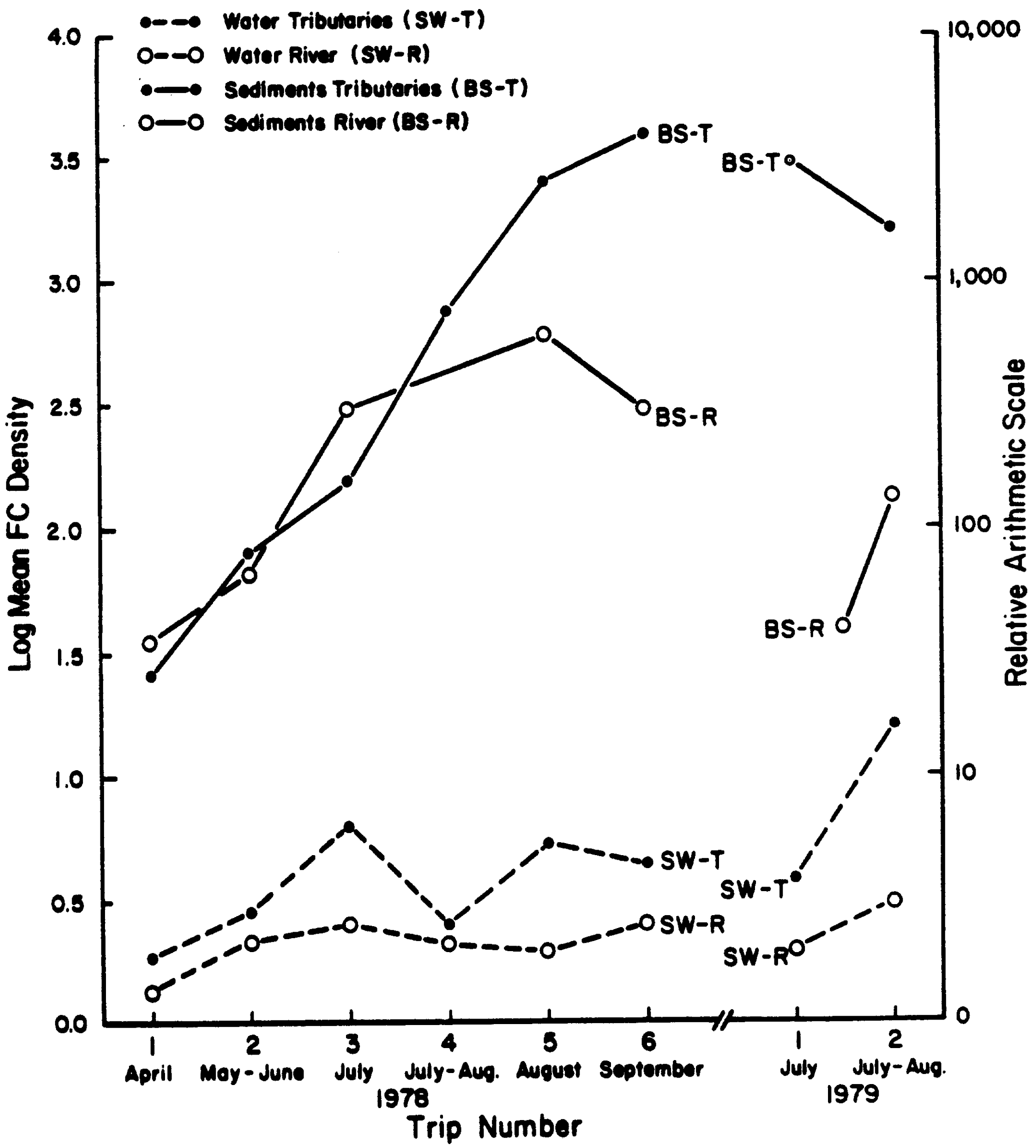


Figure 27. FC Densities in Surface Waters and Bottom Sediments of Both the Colorado River and its Tributaries during 1978 and 1979 Research Trips.

Plotted values are log mean FC densities for each research trip representing all corresponding trip samples.

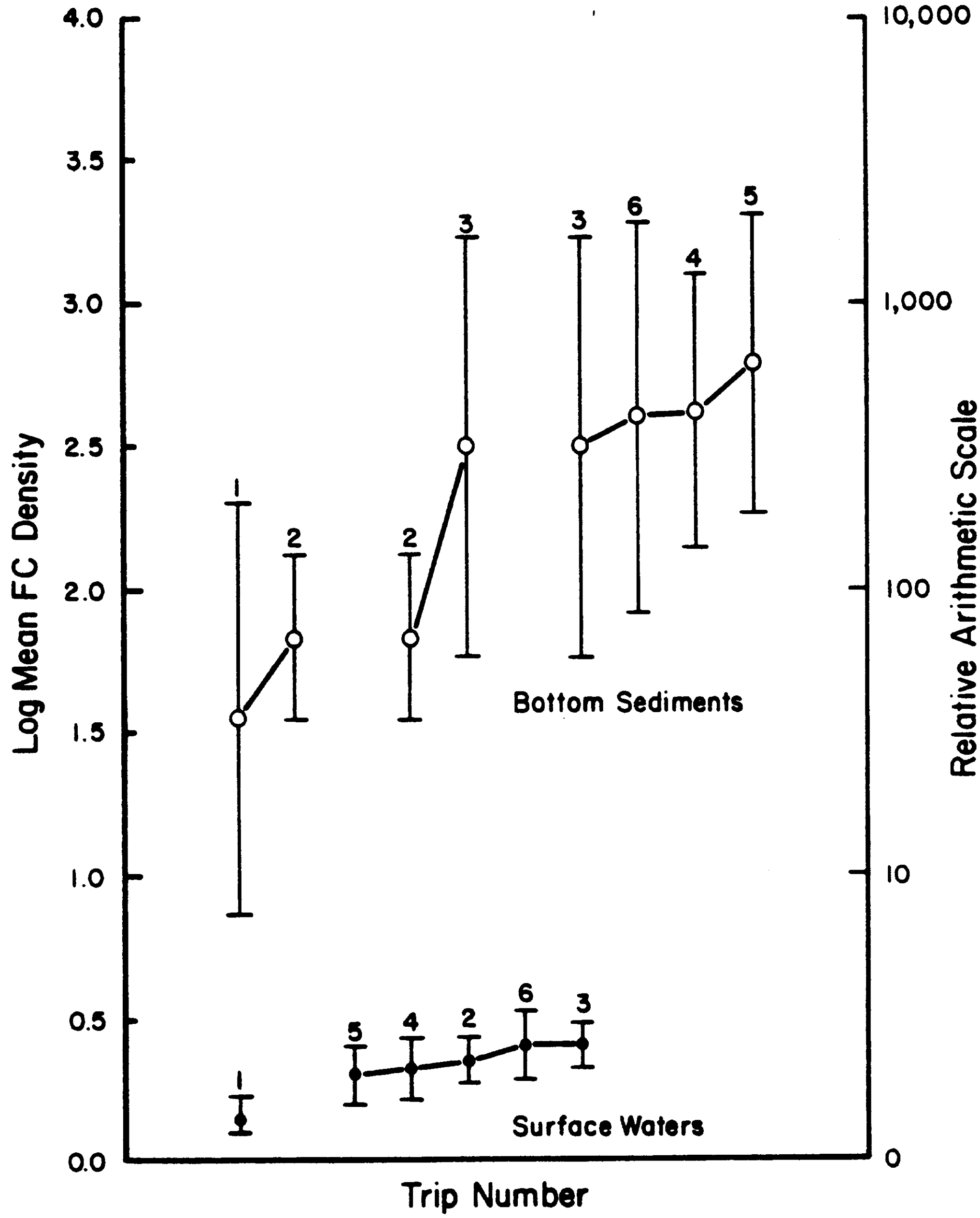


Figure 28. LSD Examination of 1978 Trip Log Mean FC Densities in Colorado River Bottom Sediments and Surface Waters.

Significance levels equal 0.05; vertical bars indicate 95% confidence interval of the trip log mean.

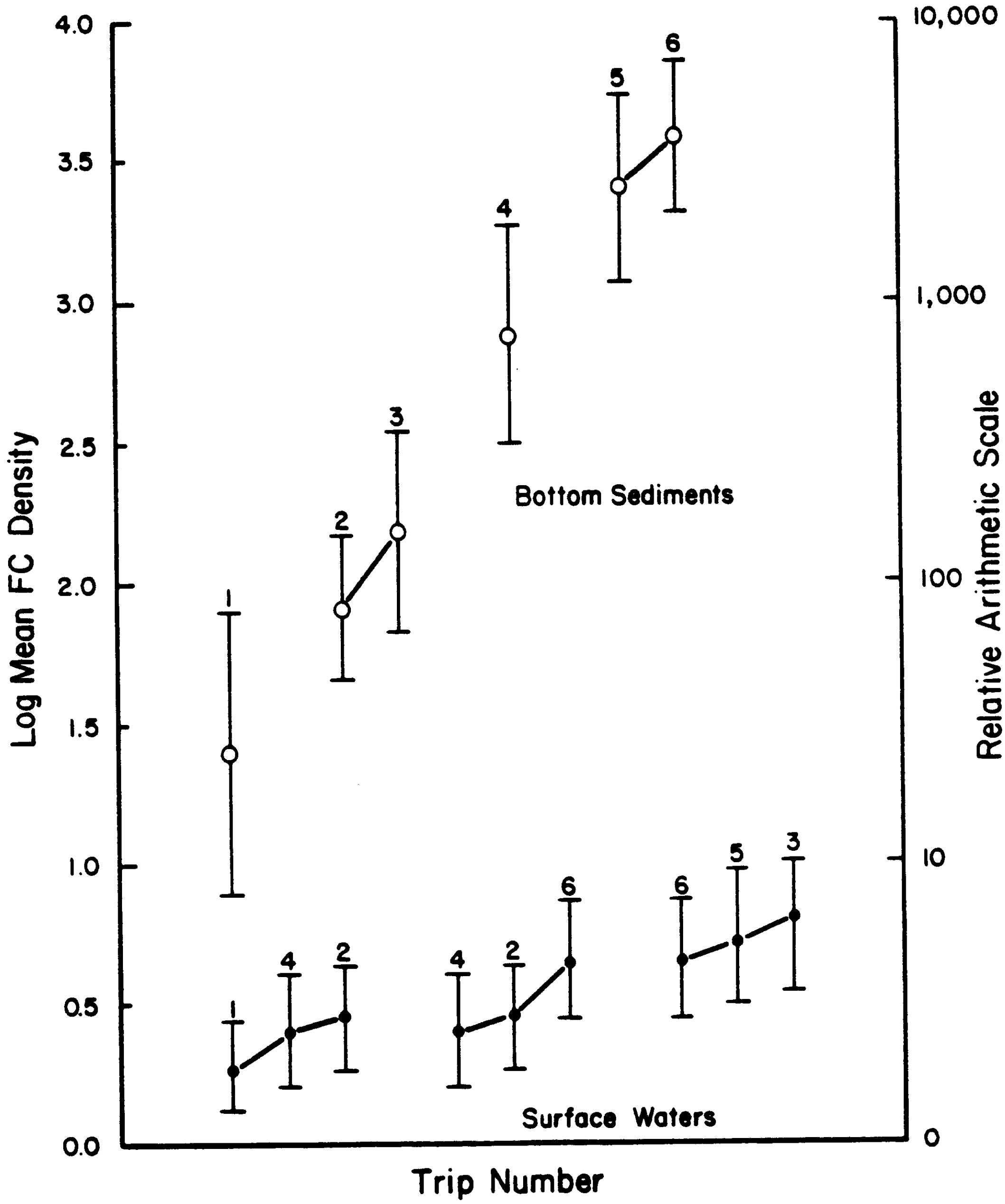


Figure 29. LSD Examination of 1978 Trip Log Mean FC Densities in Colorado River Tributary Bottom Sediments and Surface Waters.

Significance levels equal 0.05; vertical bars indicate 95% confidence interval of the trip log mean.

V. DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Guided by specific objectives, this research has been designed to examine selected water quality parameters in the Colorado River corridor of the Grand Canyon; the findings of the research are finalized in this section. Examination of recreational water quality profiles of the Colorado River and tributaries focuses on bacterial parameters which indicate the relative potentials for health hazards associated with fecal contamination of the water resource. Chemical and physical parameters are of less critical significance to recreational use of the river and tributaries and the profiles of these elements established in Section IV are not further elaborated in this discussion. Water quality implications for river runners and river corridor hikers and for managers of white water recreational resources have been included in the discussions. Specific references are to the Grand Canyon but many findings may have significance for river runners and managers on other recreational rivers.

A. DISCUSSION

Research analyses have determined that the key to a comprehensive understanding of recreational water quality in the Colorado River corridor is a clear and accurate perspective of the relationship between surface water and bottom sediment water quality. Surface water and bottom sediment microbial quality must be mutually examined to provide an accurate analysis of the status of recreational water resources. In practice, however, analyses have almost always been confined to surface water investigations; bottom sediments have rarely been recognized as critical elements in the comprehensive recreational water quality profile.

To present Colorado River corridor water quality, three steps are taken: 1) surface water quality is discussed in absence of reference to bottom sediments, a traditional, but incomplete, profile; 2) the role of bottom sediments in the water quality profile is examined; and 3) the significance of surface water-bottom sediment interactions are evaluated.

1. Surface Water Quality

a. Colorado River Surface Water Quality

Discussion of Colorado River surface water quality is divided into: (1) recreation contact and drinking water quality; and (2) variations in river surface water quality.

(1) Recreation Contact and Drinking Water Quality

Surface water FC data for the Colorado River during the 1978 and 1979 research seasons show a high quality recreation water status for full body contact based on established State and Federal water quality standards (200 FC/100 ml, Table 18).

The 1978 log mean FC density in the river of 2.1 FC/100 ml and the 1979 mean of 2.4 FC/100 ml are well below the 200 FC/100 ml contact standard. Only twice in 497 collective observations over two seasons did individual sample FC densities exceed the contact standard.

River surface water is not of potable quality as compared to drinking water standards (Table 18); two years of sampling show low FC densities to be present in most of the waters throughout the river running season. Treatment, therefore, is recommended to assure drinking water standards. NPS recommends treatment via eight drops of liquid chlorine bleach per gallon of water or proper use of a commercial treatment product such as iodine tablets.

Analysis of the relative ratios (0.10) of FC and FS densities in the river surface water indicates animal rather than human fecal matter as the primary source of contamination. Although evidence of human sewage in water is usually regarded more seriously, animal fecal waste can represent a significant health hazard. Enteric diseases known to infect man, as salmonella, also occur in other warm-blooded animals, such as cattle, mules, and wildlife. The FC/FS ratios and the low FC densities in the surface waters suggest that the human sewage carry out programs and other sanitary procedures of handling fecal waste by river runners have minimized human fecal contamination of the river.

(2) Variations in River Surface Water Quality

The 1978 and 1979 data show significant variations in Colorado River surface water quality to be infrequent; 75% of the samples show FC densities of 3 FC/100 ml or less (Figures 15 and 21, Sections IV.D.1.a and IV.D.2, respectively). FC densities which exceed these minimal levels are not consistently associated with intensive use beach sites, tributary inflows, mid-channel or river bank positions, or time of day. Indicator bacteria are fairly uniformly distributed throughout the river channel.

The preceding research findings are significant in that they reflect surface water quality conditions that prevail in Grand Canyon throughout much of the year. These findings may not be representative of all surface water quality conditions as an unseasonably dry climate and resultant low levels of watershed flushing and stream bed turbidities persisted during both research seasons. One river sample period, 0800 hours on 8 September 1978 at mile 83, suggests the potential impact on surface waters of intensive summer rainfall and watershed flushing. Research records show that following a thunderstorm on 7 September 1978, river turbidities escalated from 8 FTU to 100 FTU and surface water FC densities reached 1165 FC/100 ml. Opportunities to assess surface runoff events are rare for 1978 and 1979 surface water data; consequently, the impact of summer precipitation on surface water quality cannot be fully determined.

Tributary inflows had no detectable influences on Colorado River water quality, but the 1978-1979 findings cannot be considered conclusive on this possibility. Storm runoff representing tributary watershed flushing was not observed and only normal base flow was sampled from side streams. Some side stream flows had relatively high FC densities but the dilution factor of the river apparently nullified the effects of the inflow. Tributaries should, however, be considered as potentially significant sources of fecal contamination to the river in the event of storm flow.

There is evidence that the first 40 river miles are less contaminated than remaining downstream reaches (Figure 26, Section IV.E.1). Cumulative downstream inputs from river bottom sediment resuspension and side streams are probable explanations of the slight increase in downstream FC distributions. These differences are statistically real and probably reflect real processes but in terms of practical management and river runner concerns they are insignificant. Log mean FC densities are sufficiently high to require treatment of drinking water but do not represent a surface water recreational contact hazard.

Surface water turbidity is a factor which shows an apparent association with relatively high surface water FC densities. Mean turbidity for 28 samples from 1978 and 1979 with FC densities of 10 FC/100 ml or more is 40.7 FTU compared to a mean turbidity of 19.0 FTU for all river samples. Correlation between turbidity and surface water FC densities is an expected phenomenon. Turbidity in the Colorado River is a result of bottom sediment resuspension or storm runoff from tributary watersheds, processes which potentially introduce increasing numbers of bacteria into the river surface waters.

During the 1978 and 1979 research seasons, storm runoff from tributaries was infrequent and bottom sediment resuspension within the river channel was predominantly responsible for turbidity in the Colorado River. Bottom sediment resuspension was a function of river velocity and wetted surface area; accordingly, daily high river stages were more turbid than daily low flows.

b. Tributary Surface Water Quality

Tributary surface water is similar in recreational quality to Colorado River water based on composite analyses of FC densities in 26 tributaries in 1978 and 9 tributaries in 1979 (Figure 22, Section IV.D.3 and Figure 23, Section IV.D.4). Recreational contact quality is high;

the 1978 and 1979 composite log mean FC densities, 3.6 FC/100 ml and 8.0 FC/100 ml respectively, are well below the 200 FC/100 ml recreational contact standard. Log means, representing 1978 and 1979 data, for the five tributaries with some individual observation in excess of the contact standard are less than 20 FC/100 ml (Table 20), indicating favorable overall full body contact quality.

Table 20. Log Mean FC Densities in Individual Tributaries with Some Individual Observations Exceeding 200 FC/100 ml.

Tributary	Total Number of Observations	Number of Observations > 200 FC/100 ml	Log Mean FC Density
Three Springs	2	1	3.3 FC/100 ml
Hermit Creek	29	2	4.2 FC/100 ml
Havasu Creek	22	2	11.5 FC/100 ml
Elves Chasm	13	1	12.9 FC/100 ml
Diamond Creek	5	1	18.8 FC/100 ml

Drinking water quality standards can only be assured for tributary water with treatment. Inner canyon springs such as Vasey's Paradise and Tapeats Creek which are popularly considered "safe" drinking water have shown evidence of fecal contamination.

A 1978 composite FC/FS ratio (0.06) for all tributaries indicates wildlife and/or livestock to be the predominant sources of fecal contamination in tributaries.

Examination of the composite data (Figure 22, Section IV.D.3 and Figure 23, Section IV.D.4) showed that low FC densities were predominant in all tributaries including the five listed in Table 20, demonstrating similar surface water quality status among side streams. However, only a limited number of sample observations per individual side creek were available (due to logistical constraints) and watershed characteristics of some tributaries suggested that more severe surface water quality conditions may have been detected.

Two inner canyon tributaries, Hermit and Havasu Creeks, are intensively used recreation sites and their surface waters are traditionally considered suspenct for drinking water by river runners. Surface water data show predominantly high quality recreational contact waters (Figures 24 and 25, Section IV.D.4) but watershed characteristics suggest the potential for far more critical conditions. Both creeks drain narrow canyons in which relatively intensive human activity is restricted to the stream corridors. Hermit and Havasu are popular with backpackers; Havasu also receives significant use from river runners and drains the Havasupai Indian reservation as well. Human feces are evident on occasion in the near vicinity of each water course. A field toilet, to accommodate use at Hermit, removes solids but passes liquid effluent into a leach field system.

With potential sources of fecal contamination evident in both the Hermit and Havasu Creek watersheds, the 1978 and 1979 data may not accurately reflect the range of surface water quality conditions possible in these creeks. Unfortunately, direct storm runoff was sampled only once, at Havasu on 7 August 1979; the remaining 49 samples were of base flow. The 7 August 1979 Havasu samples showed FC densities of 530 and 510 FC/100 ml, indicating a potential for more severe water quality conditions.

Three tributaries--Paria River, Little Colorado River, and Kanab Creek--drain extensive outer canyon watersheds and potentially may have highly contaminated storm water runoff. Data show surface waters with high recreational contact quality but do not reflect observations of storm water flows. Management and river runners should not overlook possible water quality problems associated with storm runoff usually evidenced by above-average turbidity.

2. Bottom Sediment Quality

Bottom sediment findings are in sharp contrast to the water quality status indicated by surface water data alone. Colorado River corridor water shows excellent full body recreation contact quality status; viewed from the perspective of bottom sediment analyses, an entirely different picture of Colorado River corridor recreational water quality is formulated. The river and tributaries are not as free of fecal contamination as surface water analyses alone would suggest; significant densities of FC bacteria are found in the bottom sediment material, indicating an ever-present latent source of enteric contaminants which may, upon resuspension, degrade surface water quality. The Colorado River and the tributaries show similar bottom sediment water quality conditions.

a. Colorado River Bottom Sediment Quality

Concentrated densities of FC bacteria occur in Colorado River bottom sediments (Figure 27, Section IV.E.2). Densities of FC bacteria in river sediments vary widely from site to site (Figures 19 and 20), Section IV.D.1.c; Figure 21, Section IV.D.2) but show a definite pattern of increase through the river running season (Figure 19, Section IV.D.1.c and Figures 27 and 28, Section IV.E.2). The significance of bacteria populations in bottom sediments is undetermined in reference to quality standards; water quality standards for bottom sediments are not yet established for the analyses of recreational waters. To facilitate understanding and recognition of the importance of indicator organisms in Colorado River and tributary sediments, an examination of the processes that affect the distribution of enteric microbes in the river surface water and bottom sediment is presented. These processes are not definitively known but reasonable speculation based on available data and observation can suggest probable mechanisms. Following is a discussion of the distribution of FC bacteria in the Colorado River environment. Specific references are to the river but the concepts also have significance for the tributaries and potentially other natural streams as well.

(1) Source of FC Bacteria in the River Environment

The predominant, initial sources of FC bacteria in the river sediment and surface waters are warm-blooded animals external to the aquatic environment. Aquatic animals (fish and amphibians), reptiles, insects, soil, and vegetation are not apparent sources of FC bacteria (Geldreich, 1966). FC/FS ratios (0.10) in the river surface water indicate warm-blooded animals other than man as the primary sources of fecal organisms. Some beaver are found in Grand Canyon and obviously deposit fecal matter in the river; terrestrial wildlife, by virtue of population, may make the most significant contributions of fecal organisms to the river system. Fecal material and/or organisms deposited on the Grand Canyon watershed can be transported to the river via the surface movement of water. Livestock may have an impact through tributary flows; commercial pack mules, in the Bright Angel Trail-Phantom Ranch area, and birds may also contribute. Though data indicate other probabilities, human waste cannot be totally discounted from the river environment. All of the preceding types of fecal matter when present in water represent potential hazards to river runners using the Colorado River.

FC densities in river surface waters are predominantly low, suggesting a rate of fecal organism introduction into the river which does not create a critical surface water quality problem. FC bacteria in the bottom sediments must initially enter the river environment via surface waters but achieve high population densities which do not at all reflect the situation in the overlying waters; therefore bacteria must be concentrating in the sediments.

Surface water densities do not initially appear high enough to be suggested as the source of FC bacteria to the bottom sediments, but a transformation of the surface water densities clarifies this potential. Assuming the distribution of bacteria in the surface water to be uniform, the 1978 log mean FC density of 2.1 FC/100 ml equals 600 FC bacteria/ft^3. Flows of 20,000 cfs are not uncommon in the Colorado River during midsummer; at this flow rate and a 2.1 FC/100 ml density, 12 million FC bacteria occupy the cross sectional volume of water which passes any given point along the river channel each second. These numbers are estimations, based on an extrapolation of the 1978 log mean FC density, which suggests that FC bacteria are present in the Colorado River surface water in sufficient numbers to produce the FC densities observed in the bottom sediments.

(2) Distribution of FC Bacteria in the River Environment

Data show FC bacteria to be fairly uniformly distributed in both the river surface waters and bottom sediments (Figure 13, Section IV.D.1.a and Figure 18, Section IV.D.1.c) but sediment FC populations are concentrating through time while surface water FC populations are not (Figure 27, Section IV.E.2). Based on knowledge of the Colorado River system and available data, three processes which may be active in concentrating bacteria in the bottom sediments include: (a) sedimentation of bacteria from surface waters; (b) sediment filtration of bacteria from surface waters; and (c) persistence of bacteria in sediments. These processes are speculative scenarios; other unidentified elements may be involved.

(a) Sedimentation of Bacteria

Turbulence and flow velocities of the Colorado River are too great to allow significant numbers of freely suspended bacteria, with specific gravities essentially equivalent to water, to reach the bottom material by sedimentation. Sedimentation may have a role in the translocation of FC bacteria attached to particulate matter; bacteria tend to adhere to positively charged surfaces of suspended particulates and by virtue of the greater mass of the particulate matter bacteria may be deposited on the bottom by sedimentation. Fine sand is usually positively charged; cations, such as Ca^{++} and Na^{+}, are available in the river water to provide linkages to negatively charged surfaces. Particulate matter is commonly cycled by the turbulent action of the river from the bottom material through the water column and redeposited as sediment, a continuous process in the river which may provide a mechanism to concentrate bacteria in the bottom sediments.

(b) Sediment Filtration of Bacteria

Sand filters are effectively used to remove bacteria from water in water treatment plants; a similar action may be responsible for the buildup of FC bacteria in stream bottom sediments. In the Colorado River, two sand filtration processes may be at work: filtration associated with stream flow and filtration associated with fluctuating river stage. Flow velocities through the bottom sediments are relatively much lower than in the overlying channel but an exchange between bottom materials and surface water does occur (Hynes, 1972). The flow rate may be sufficient to allow bacteria to concentrate in the sediment through a continuous filtration process.

Through the summer season, significant daily stage fluctuations occur in the Colorado River (Figures 8 and 9, Section IV.B.1). With each daily rise and fall of the river level, beach sediments are flooded and drained. Beaches with shallow slopes experience this activity over areas tens of feet wide. As the river stage falls and water drains through the beach sediments, water-borne bacteria are probably retained in the sediments. Through the continual resupply process of daily stage fluctuations, bacteria could be expected to concentrate in the sediments.

The seasonal increase of FC bacteria in bottom sediments can be speculatively linked to the sedimentation and filtration processes. Enteric bacteria may be more abundant in the Grand Canyon water resources during the summer as human and animal activity, especially near water courses, is higher than winter periods; recreational activity is reduced in winter and wildlife find water in streams and cachements away from the inner corridor but dry in summer. Potential for watershed flushing of the fecal matter and organisms and sediment under the summer rainfall regime, which produces relatively more overland flow than snowmelt, may also be high. Sedimentation action is enhanced by watershed flushing which introduces suspended sediment to the stream and by increased summer flow rates and associated bottom sediment resuspensions. Filtration action is favored by summer flow rates which will increase interstitial substrate flow and by increased stage fluctuations which are the engine of the beach drainage process.

(c) Persistence of FC Bacteria in Bottom Sediments

Enteric bacteria probably experience prolonged survival extending for several weeks in the Colorado River bottom sediments. FC bacteria in porta potty dumps in moist beach sands along the Colorado River were found to persist for periods of several months (Phillips and Lynch, 1977). Extended survival of some enteric pathogens and indicator organisms in contaminated soils have been reported for a variety of temperatures and moisture conditions (Phillips and Lynch, 1977). Low temperatures (8 to 12°C) of Colorado River sediments slow microorganism metabolic rates and the sediment environment provides nutrient and substrate advantages to microorganisms; processes which collectively facilitate survival. Coupled with sedimentation and filtration actions, persistence of enteric organisms in bottom sediments could have led to the high FC densities observed in the Colorado River.

Reproduction of FC bacteria cannot be discounted as a cause of bacterial concentrations in bottom sediments but is considered unlikely. Colorado River sediments are relatively nutrient-poor and cold (8-12°C) compared to the nutrient-rich and warm (approximately 37°C) native environment of enteric organisms. Matches and Liston (1966) report growth of <u>Salmonella</u>, an enteric pathogen, at temperatures comparable to the Colorado River; however, the experimental medias were nutrient rich. The growth phenomenon, if significant in bottom sediments, can be expected to be extended to both pathogens and indicator bacteria; therefore the relative importance of observed densities of FC bacteria is not affected.

b. Tributary Bottom Sediment Quality

Densities of FC bacteria in tributary bottom sediments are, in general, many times those in the overlying surface waters (Figure 22, Section IV.D.3; Figure 23, Section IV.D.4); the 1978 log mean FC density for tributary bottom sediments of 422 FC/100 ml is in contrast to the 1978 surface water log mean of 3.6 FC/100 ml. FC densities in bottom sediments of individual tributaries varied significantly from the overall mean; the lower extreme, Crystal Creek, is represented by a 1978 log mean density of 26 FC/100 ml, and the upper extreme, Hermit Creek, is represented by a 1978-1979 log mean density of 2130 FC/100 ml. A clear trend among tributary bottom sediment FC densities is an overall increase, through the 1978 river running season, to a mean level approximately 10^3 times the mean surface water densities (Figures 27 and 29, Section IV.E.2).

(1) Processes Influencing the Distribution of FC Bacteria in Tributaries

Bottom sediment and surface water quality status of the tributaries closely parallels the pattern observed for the Colorado River. Apparently, processes similar to those in the river are functioning in the tributaries and lead to the now characteristic, of Grand Canyon, distribution of enteric organisms in bottom sediments and surface waters. Sedimentation, filtration, and persistence of bacteria are processes identified in association with river FC distributions; each may also have a role in the tributaries.

An extrapolation of the tributary log mean FC density for surface waters can be made, as for the Colorado River. Tributary flow regimes are highly variable from nonexistent to stormflows of several hundred cfs. For estimation purposes, a minimum base flow of 1.0 cfs (not uncharacteristic of the 1978 and 1979 dry seasons) is assumed. Based on the 3.6 FC/100 ml composite log mean density and a 1.0 cfs volume, 1030 FC bacteria in the surface water pass any given tributary location each second. This estimate is purely ballpark for any specific tributary but does provide a seasonable reference point from which to discuss bottom sediment FC densities.

(a) Sedimentation of Bacteria

As in the Colorado River, tributary concentration of FC bacteria in bottom sediments may proceed by sedimentation. Base flow of tributaries is relatively free of suspended sediment. Without suspended particulate matter in the surface water column to serve as ballast, translocation of bacteria to the bottom by sedimentation may be fairly ineffective. During storm runoff with attendant increased in surface water turbidities, sedimentation may be more functional.

(b) Bottom Sediment Filtration of Bacteria

Tributary flows are relatively small volumes with respect to the river and, through the turbulent processes of stream flow, a significantly large portion of the low volume flow comes in contact with the bottom sediments. Consequently, a relatively high rate of exchange between the water column and interstitial bottom sediment flow can lead to filtration of FC bacteria from the surface waters by the sediment material. Over the course of a summer season, concentrations of bacteria could build in the sediments until flushed out by periodic floods or until depreciated by die-off over the winter period.

(c) Persistence of Bacteria

Although tributary temperatures are warmer (25 to 35°C in late summer) than the 8 to 12°C temperatures of the Colorado River, bacteria persistence in bottom sediments is likely to be an important factor facilitating the concentration of enteric organisms in tributary bottom sediments. Prolonged survival of enteric organisms have been reported in soils of 25 to 35°C (Phillips and Lynch, 1977).

(2) Comparing Tributary Bottom Sediment FC Densities

Bottom sediment data may provide insight to tributary water quality not obtainable from surface water analyses alone. Surface water data indicate that Grand Canyon tributaries all have similar water quality status, but diverse characteristics of tributary watersheds suggest that water quality differences could be expected. Tributary watersheds vary in size and land use. Some tributaries drain extensive outer canyon areas; other tributary drainages are small and confined within Grand Canyon. A diversity of land uses which may impact water quality occur on tributary watersheds in varying levels of intensity, including: livestock grazing, water-based recreation, pack mule trains, human settlements, and wildlife habitats. Watershed factors such as slope, aspect, vegetation type and coverage, and soil type can also affect water quality impacts.

Log mean bottom sediment FC densities (Table 21) show significant differences among tributaries, potentially reflecting diverse watershed characteristics and land uses. Bottom sediment FC densities cannot be directly linked to specific sources of water quality impacts but can be considered, with reasonable certainty, as results of variable inputs of fecal organisms to the tributaries in response to watershed patterns of contamination. In contrast to surface water findings, bottom sediment data are evidence that tributary water quality status in Grand Canyon is diverse and that surface water quality may potentially be impaired by watershed sources of fecal contaminants. Management may consider bottom

Table 21. Log Mean FC Densities in Tributary Surface Waters and Bottom Sediments.

Tributary	Sample Population	Log Mean FC Density (FC/100 ml)	
		Surface Waters	Bottom Sediments
Paria River	6*	5.5	1744
Nankoweep Creek	6*	1.3	1175
Little Colorado River	7**	1.3	117
Clear Creek	6*	1.9	638
Bright Angel Creek	7**	8.6	1238
Garden Creek	6**	4.9	351
Monument Creek	5*	1.4	378
Hermit Creek	19**	4.2	2130
Boucher Creek	6*	0.0	119
Crystal Creek	6*	0.0	26
Shinumo Creek	8**	1.8	174
Elves Chasm	8**	12.9	734
Stone Creek	6**	1.7	353
Tapeats Creek	6*	1.2	334
Deer Creek	14**	2.3	417
Kanab Creek	6*	2.9	241
Olo Creek	5*	8.7	649
Matkatamiba	8**	2.3	503
Havasu Creek	14**	11.5	608
Fern Glen	5*	1.5	71
Diamond Creek	6*	17.0	1296

*1978 data

**1978 and 1979 data

sediment data not only as evidence of current water quality impacts but also as indicators of potential impacts. The use of bottom sediment FC densities as water quality indicators in a monitoring program of the Colorado River corridor is considered in a following section (V.A.2.d).

c. Bottom Sediments as a Water Quality Hazard

Sediment concentrations of enteric organisms become a hazard only when sediments are resuspended or contacted directly by people. Avenues of intermixing sediments and surface waters in Grand Canyon include man-induced and natural phenomena. Water play by recreationists, beaching and launching of rafts, operation of boat motors, collection of drinking and cooking water by waders, and dish scrubbing using sediments as abrasives are activities which can bring humans in contact with sediments or sediment resuspensions. These actions generally represent localized and temporary sediment disruptions; river runners and hikers can avoid surface water quality impacts by avoiding the sediment cloud suspended in the water. Water play, particularly in tributary pools, can lead to widespread sediment suspensions in surface waters; activities may have to be restricted if sediment contact is unavoidable.

Surface water and bottom sediment samples from Elves Chasm, collected on 5 August 1979 during the water play activity of approximately 50 river runners which created visible turbidity, showed 4810 FC/100 ml in the surface waters and 9200 FC/100 ml in the bottom sediments. The pool at Elves Chasm has low flow rates, except at a narrow outlet, so sediment disturbed by swimmers and waders at that site and upstream remains in the pool for a period of time before settling or being carried downstream. Visible turbidity in water at a pool, as at Elves Chasm, is a warning to recreationists that water quality hazards can exist and water play may not be advisable.

Natural processes which resuspend bottom sediment material and disperse it throughout the water column include normal channel flow and storm water runoff. Normal channel flow of the Colorado River is characterized by fluctuating stage heights; turbidity increases moderately in a daily cycle as a function of increasing stage and corresponding increases in flow velocities and turbulence. Based on 1978 and 1979 data, turbidities associated with normal channel flow do not impair river recreation contact quality but emphasize the need for drinking water treatment.

Storm water runoff can dramatically increase turbidities in the river or side streams. Highly turbid runoff flows can exceed bacteria contact standards; refraining from water play is the only way to be assured of avoiding contact water quality hazards. Treatment of highly turbid water used for drinking is essential.

d. Bottom Sediments as Water Quality Indicators

Concentrations of FC bacteria in bottom sediments can be more important indicators of potential water quality hazards than are surface water data alone. Bottom sediment data reveal potential hazards within the stream sediment material itself and, as demonstrated by comparing tributary watersheds via bottom sediment analyses (Table 19, Section V.A.2.b.(2)), provide indications of watershed potentials to affect water quality. Sediment concentrations of FC bacteria are somewhat persistent, remaining at fairly stable density levels for periods of days or weeks; consequently bottom sediment samples are representative of time intervals extending before and after the time of sampling. In contrast, surface water analyses do not measure bottom sediment water quality hazards and reflect watershed inputs to the stream channel only at the times of sampling. Surface water sampling must be conducted on a fairly intensive time series basis to establish a water quality perspective on a broad time spectrum.

Bottom sediment analyses would be an essential part of a water quality monitoring program for the extensive Colorado River corridor. Sediment sampling would accomplish two important functions: 1) the level of water quality hazards concentrated in the river and tributary sediments would be traced through the river running season; and 2) tributaries could be effectively monitored by the limited number of management float trips possible through the Canyon.

Data from 1978 show a clear tendency for FC densities in river and tributary sediments to increase through the river running season; FC densities late in the season reached levels indicating much more significant water quality hazards in the bottom sediments than appeared early in the season (Figure 27, Section IV.E.2). A bottom sediment monitoring program can keep management advised of the sediment situation so that appropriate safeguards may be taken if necessary.

Water quality monitoring float trips through Grand Canyon would probably be limited in number. Through bottom sediment analyses of key tributary sites, potential problem areas could be effectively identified by two or three trips per season. Though limited in number, the bottom sediment samples would be indicative of water quality status which could be expected to prevailfor some time after the sampling. For example, if high FC densities in the sediments at Elves Chasm were detected at the end of July, a water quality hazard could be expected to persist or even increase at that site through the duration of the summer season.

3. Significance of Surface Water-Bottom Sediment Interaction

Research findings clearly show the dichotomy between surface water and bottom sediment FC densities in Grand Canyon; fecal organisms introduced to the surface waters persist and concentrate in the sediment material establishing population densities which, if resuspended, can significantly degrade overlying surface water quality. This phenomenon, which occurs throughout Colorado River corridor water resources, is not newly discovered or restricted to Grand Canyon; this research team reports similar findings for a variety of Arizona lakes and streams representing dispersed and developed day use recreation as well as second home developments (Brickler et al., 1976; Winslow, 1976; Brickler et al., 1977; and Brickler and Morse, 1979). Grand Canyon research extends recognition of the surface water-bottom sediment water quality relationship to an extensive, remote river-tributary system of wildland-wilderness character. The processes which create bottom sediment concentrations of enteric organisms are not unique to Arizona and can be expected to be operating in a diversity of natural waters. Collectively, these bottom sediment findings have broad implications for natural resource recreation-based water quality analyses; surface water analyses alone should not be considered sufficient to determine the water quality status of recreational lakes and streams. Managers of wild rivers used for recreation should be particularly alerted by the Colorado River corridor water quality status in Grand Canyon as they may expect similar types of processes within their river resources. Bottom sediment analyses must complement surface water examination to provide an accurate water quality perspective. Surface water analyses which confirm recreational contact status for a water resource are misleading if undetected sediment concentrations of fecal organisms potentially can degrade surface water quality. Water quality standards are not yet determined to direct interpretation of bottom sediment analyses, i.e., standards which relate bottom sediment FC densities to specified water quality hazards; but sediment examinations can identify potential hazards as well as sources of surface water contamination.

Colorado River corridor water quality research supports the perspective that there is a critical need for specific standards which relate bottom sediment FC densities to water quality hazards. Bottom sediment water quality standards would: 1) promote widespread recognition among researchers and managers of the significance of bottom sediments as water quality indicators and hazards in recreational waters; 2) direct water quality research towards bottom sediment examinations; 3) serve as a reference point for interpretation of research data; and 4) establish criteria for management decisions regarding use of water-based recreation resources.

Additional research is necessary to develop appropriate bottom sediment standards. The relationship between bottom sediment FC densities and recreation water quality hazards must be quantified before specific bottom sediment standards can be determined.

B. CONCLUSIONS

1) The microbiological quality of river and tributary surface waters, during periods of low turbidity, are generally acceptable for recreation activities, including full body contact. There is a high probability of surface water degradation if activities re-suspend sediments, especially in tributary pools where intensive use and flow characteristics can temporarily concentrate sediment suspensions.

2) Research indicates that turbid storm water flows in the river or tributaries have a high potential for significant microbiological contamination. Additional water quality analyses are necessary to confirm this phenomenon.

3) When not carrying storm water runoff, tributary inflows in the summer season have not shown any detectable effects on Colorado River surface water microbiological quality.

4) Regardless of turbidity levels or collection location, surface waters of the Colorado River and tributaries require treatment to assure drinking water standards.

5) Enteric organisms are concentrated in the bottom sediments of the Colorado River and tributaries at levels which represent microbiological water quality hazards to river runners and other recreationists using the water resources of the Colorado River corridor. If disturbed, bottom sediment FC densities can degrade surface waters beyond microbiological contact standards; suspended sediments can impair the ability of water treatment techniques to assure microbiological drinking water standards.

6) Surface water analyses alone cannot be considered sufficient to determine the water quality status of recreational streams and lakes; bottom sediment analyses must complement surface water examinations to provide an accurate water quality perspective.

7) Based on 1978 data, the chemical water quality status of the Colorado River and tributaries, with few exceptions, reflects conditions which are in line with those expected of natural waters.

8) Bottom sediment water quality standards are needed for evaluation and management of natural recreation waters. Research effort should be extended to quantify the relationship between bottom sediment FC densities and recreation water quality hazards.

C. RECOMMENDATIONS

Based on the findings of this research, recommendations are offered in two categories: 1) water quality and recreation float trip use of the Colorado River corridor, and 2) water quality monitoring and research in the Colorado River corridor.

1. Water Quality and Recreation Float Trip Use of the Colorado River Corridor

Water quality hazards in the Colorado River and tributaries are primarily associated with a) bottom sediments, b) turbid storm water runoff, and c) drinking water.

a) Surface waters of the Colorado River and tributaries are generally acceptable as full body contact resources if no turbidity is visible; water play presents a paradox to this situation. Bottom sediments are inevitably resuspended by water play activities especially in confined, shallow tributary pools with sediment characteristics as occurring at Elves Chasm or parts of Havasu Creek. Associated with sediment resuspension is a high probability of microbiological degradation of water quality, perhaps exceeding full body contact standards. Accordingly, caution and good judgment should be exercised when engaging in water play. Ideally, river runners should choose tributary pools, as at Shinumo Creek (mile 108) or in parts of Havasu Creek (mile 157), with gravel or stone bottoms or with sufficient depth to avoid resuspension of bottom sediments during water play. Water play in pools can create critical water quality hazards and use of these areas may require restrictions; river runners should cease activities which dislodge the bottom sediments or exit water when turbidity becomes visible in the surface waters. Total submergence of the body is associated with the highest risk of ingestion of surface waters, and as a minimum precaution, should be avoided if visible turbidity is present. Indiscriminate and simultaneous use of Elves Chasm by large groups of people will cause significant sediment disruption; intensive water play should therefore be restricted.

Water play activities generally will have less critical impacts on Colorado River surface water quality than in tributaries. The currents and volume of the river quickly disperse suspended sediment and cold water temperatures usually discourage most river runners from prolonged, concentrated water play. In some shallow, quiet flow areas, as at Redwall Cavern (mile 33), the action of people and/or boats could combine to create significant sediment suspensions and prudent river runners should avoid total submergence contact.

b) Storm water runoff combines the water quality hazards of bottom sediment resuspension from flood level flows and watershed flushing. Microbiological contamination of storm water runoff is probable and full body contact in storm affected tributaries or the river is not recommended.

c) In addition to following NPS treatment recommendations for all drinking water collected from the Colorado River corridor, there are several steps river runners should take to insure the quality of their drinking water. If flowing relatively clear, the main course of the Colorado River should be used as the primary source of drinking water; collect water away from the immediate shoreline contact with beaches and avoid sediment cloud suspension occurring from wading or upstream disturbances. The volume of water in the Colorado River acts to dilute the impacts of contamination which could occur; small tributary flow volumes do not provide this advantage.

Tributaries are secondary choices for drinking water sources and are not to be used unless the Colorado River is heavily sediment laden from Canyon storm water runoff, as when the Little Colorado River is in flood. Tributaries could be used as alternative sources provided they are flowing clear. Side creeks which should always be avoided as sources of drinking water include: Paria River, Little Colorado River, Bright Angel Creek, Garden Creek, Hermit Creek, Elves Chasm, Havasu Creek, and Diamond Creek. Caution should be exercised during water collection from a tributary so as to avoid disruption of bottom sediments. Water should not be collected following human water play activities at the site or upstream. Treatment is essential before consumption.

Frequently river runners have no choice but to use turbid, sediment laden water for drinking purposes; the Colorado River is the best selection in these events. An essential process in utilizing turbid water for drinking is settling of the sediment, preferably overnight, and decanting the supernatant water into a clean container before treatment to avoid the microbial contamination often associated with particulate matter and reduce the nullifying effect sediment can have on chlorine disinfectants. Settling can be accomplished best in a deep container, such as a bucket, by pouring settled water into a clean container slowly to avoid stirring the sediment on the bottom of the bucket.

National Park Service management has taken the necessary steps (i.e., sewage carryout and sanitary procedures) to minimize impacts from river runners on the water resources in the Colorado River corridor; at this juncture no other apparent actions could be taken to reduce the microbial concentrations found in these resources. The key to coping with the water quality hazards found in the river corridor is user awareness and understanding of the existing and potential hazards. National Park Service management should institute a water quality education program to be disseminated to all inner canyon users including commercial and noncommercial river runners, Lees Ferry fishermen, and Grand Canyon backpackers. Water quality education would be a valuable addition to the annual commercial boatman training sessions. Visitors to the Colorado River corridor should know how to recognize and handle water quality problems as they occur.

2. Water Quality Monitoring and Research in the Colorado River Corridor

Water quality monitoring and additional research in the Colorado River corridor is recommended. Water quality monitoring, including bottom sediment analyses during the river running season, will keep management aware of potential water quality hazard areas; particularly popular side creek attraction sites. Monitoring processes will also provide future opportunities for critical research on the water quality implications of turbid stream water runoff; these conditions were rare in 1978 and 1979 but potentially represent significant water quality hazards.

An extension of the Colorado River water quality research is recommended for the 14-mile stretch of river between Glen Canyon Dam and Lees Ferry. Day use of this section of river by fishermen, boaters, and one-day raft trips have increased dramatically over the last few years, reaching an annual total of over 15,000 user days for 1979. Bottom sediment FC densities at Lees Ferry for 1979 show a considerable increase over 1978 levels, suggesting potential water quality hazards there and presumably upstream. Presently, the water quality status of this 14-mile section is limited; current use levels and the lack of sanitation policies suggest the potential for water quality impacts on river users as well as human impacts on the river. Research is needed to clarify this situation.

Concern for surface water-bottom sediment water quality relationships can also be extended to other water resources within Grand Canyon but away from the immediate river corridor. Bottom sediment examinations are advisable extensions of the National Park Service 208 Water Quality Project research of inner canyon streams utilized by backpackers.

APPENDIX A

FECAL COLIFORM SURVIVAL IN ICED BOTTOM SEDIMENTS

Water quality research in the Colorado River corridor of Grand Canyon included analyses of fecal coliform bacteria (FC) densities in bottom sediments of the Colorado River and tributary creeks. During the 1978 research season a field method of determining FC densities in sediments was not available; consequently, a technique was developed to preserve bottom sediment samples on ice for up to 10 days until analyses in Flagstaff, Arizona. The validity of the iced storage technique was examined by a laboratory monitoring of FC survival in iced bottom sediments for a 21-day period. Tests were performed in University of Arizona laboratories under controlled conditions which simulated field storage. Results were positive, confirming iced storage as a viable means of preserving bottom sediment samples until return from the field for laboratory analyses of FC densities.

I. BACKGROUND

Concentrations of FC have been identified in bottom sediments of streams and lakes (Van Donsel and Geldreich, 1971; Motschall, 1976; Winslow, 1976; McKee, 1977; and Morse, 1979) at densities several orders of magnitude above surface densities. Sediments are benthic environments where bacteria are apparently received by sedimentation, and concentrated through prolonged survival (Hendricks, 1971; and McKee, 1977); Hendricks and Morrison (1947) found that sediments loosely bind basal nutrients, providing an environment which facilitates the survival of enteric bacteria.

Van Donsel and Geldreich (1971) found a 90% die-off rate of FC in mud samples stored for 7 days at 20°C. Bacterial metabolism rates were of course directly influenced by the temperature of the environment; if the temperature had been close to 4°C, metabolic activity would have been greatly reduced and a much longer survival rate would have been expected. With available nutrients for maintenance metabolism, speculation suggests that viable populations of FC in bottom sediments could survive iced storage pending laboratory analyses. Some losses would undoubtedly occur, but the population examined after storage would have at least reflect the minimum density at the time of sampling.

II. RESEARCH APPROACH

Experimental determination of FC survival in bottom sediments followed a six-step procedure: A) selection of test sediments; B) sterilization of sediments; C) separation of sediments into uniform replicate samples; D) uniform inoculation of test samples with FC populations; E) iced storage of inoculated test parcels; and F) MPN analyses of FC densities in stored test parcels over a 21-day period. Figure A-1 illustrates the procedure schematically.

A. Selection of Test Sediments

Sediment material of the Colorado River corridor was predominately sand with a low percentage proportion of fine particles, silt, and clay; mechanical analyses of particle size distribution of 1978 samples are listed in Table A-1. Stream channel sediments from Sabino Canyon near Tucson, Arizona were selected for FC survival tests. Particle size distribution of the test sediments compared favorably with Grand Canyon sediment; fine particles represented 8% of the distribution.

For comparative purposes, FC survival was also examined in commercially produced glass beads with a mean diameter of 0.3 mm; the beads were essentially nutrient free. Beads were thoroughly rinsed with distilled water prior to the experiment.

B. Sterilization of Sediments

Test sediments were sieved through a coarse mesh to remove gravels > 5 mm and large organic debris such as twigs and leaves prior to autoclaving. Placed in a stainless steel pan, approximately 50 lbs. of sediment was sterilized in mass by standard autoclaving, 15 psi at 248°F for 15 minutes.

C. Separation of Sediments into Test Parcels

FC survival was examined over a 21-day period which exceeded the length of the Grand Canyon field trips by 6 to 7 days. To test the survival rate, an experimental design to approximate the Grand Canyon iced storage technique was devised. A series of sterile Whirl-Pak bags were aseptically filled with 100 ml volumes of sterile sediment; after uniform inoculation with an FC population, the bags were sealed and stored on ice in an ice chest for the period indicated in Table A-2.

The FC density in each test sample was determined immediately following the storage period. Ten replications of the bottom sediment

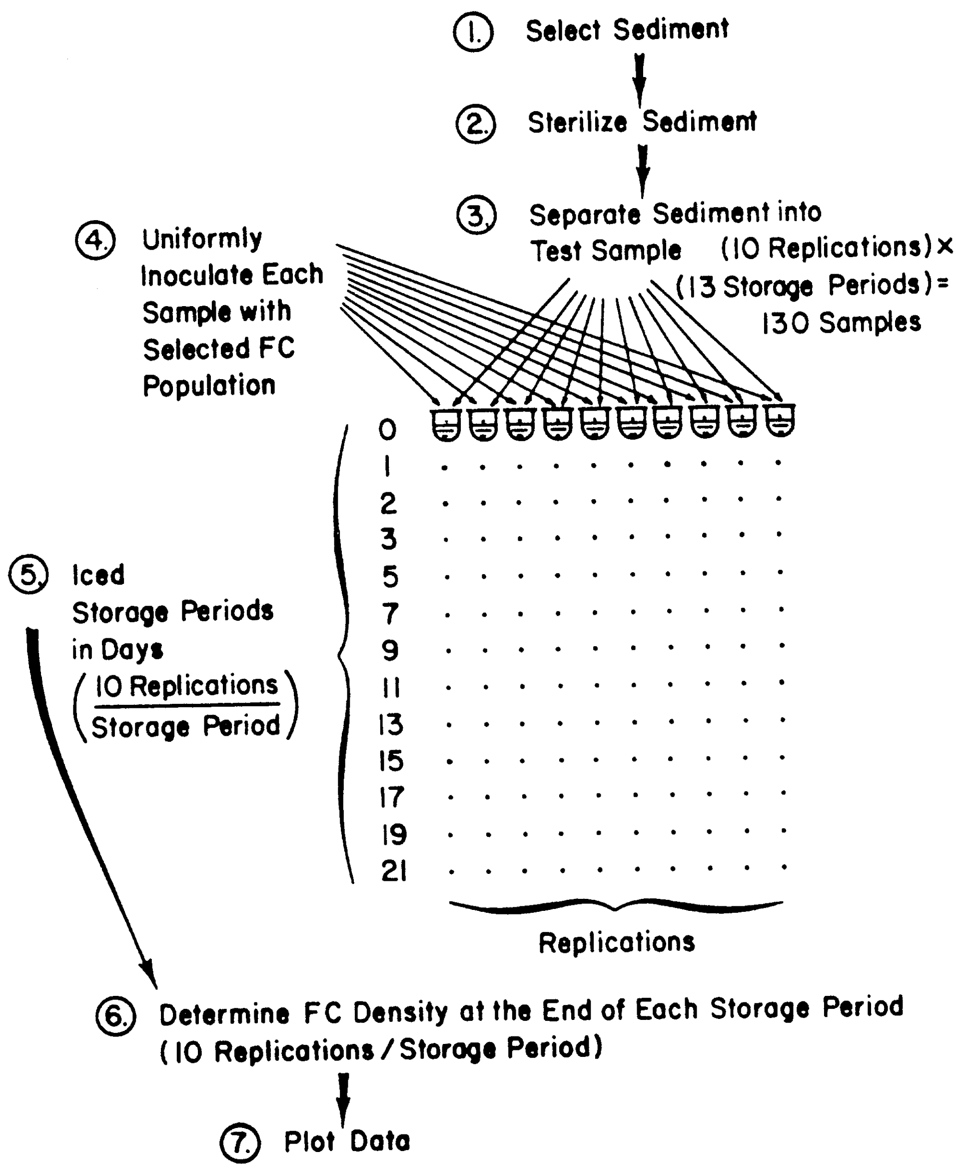


Figure A-1. Schematic of FC Survival Experimental Procedures.

Table A-1. Fine Particle Content* by Percentages of Colorado River Corridor Bottom Sediment Samples Collected in 1978.

Colorado River Samples		Tributary Samples	
Sample	% Fines	Sample	% Fines
Mile 95	14.0	Upper Hermit Creek	21.0
Mile 0	9.5	Paria River	8.5
Mile 72	8.1	Kanab Creek	8.2
Mile 166	3.4	Shinumo	7.2
Mile 69	3.0	Garden Creek	4.3
Mile 8	2.9	Tapeats Creek	3.2
Mile 108	2.6	Bright Angel	3.1

*Determined by mechanical analyses; sand = 2.0-2.5 mm, silt = 0.05-0.002 mm, and clay < 0.002 mm.

Table A-2. Storage Period of Iced Test Samples.

Bag Number (10 Replications)	Days of Storage Before Analyses
0	None
1	1
2	2
3	3
5	5
7	7
9	9
11	11
13	13
15	15
17	17
19	19
21	21

test were made to assure statistically reliable results. No replications of the glass bead test were made.

Sediment volumes were allotted to the Whirl-Paks on a weight basis. Following autoclaving ten 100 ml volumes, measured by graduate cylinder, of sediment were weighed and a mean weight determined. Test bags were each allotted the mean weight of sediment. A weighing pan and sediment scoops had been autoclaved with the sediment for purposes of measuring the sediment.

Each bag of uniform sediment volume was wetted with sterile buffered water just to the point of sediment saturation. The volume of water required to achieve saturation had been determined after the 100 ml volumes of sediment in graduate cylinders were weighed; water was added to the cylinder via buret until the soil column was saturated. Each test bag received the same saturation volume of water prior to storage.

D. Inoculation of Test Samples

Each test sample was inoculated with the same population of FC. Uniform inoculations were achieved through the following process:

1. An FC population was grown in Lauryl Tryptose Broth after inoculation from a pure culture stored on slants. Once developed, the population was centrifuged and washed three times and finally suspended in 100 ml of sterile buffered water.

2. FC density in the buffer water was approximated from an ocular density curve which related turbidity to coliform density.

3. A volume of 2000 ml of sterile buffer water was seeded with FC from the concentrated population to a density of 100,000 FC/10 ml.

4. Each test sample was inoculated with 10 ml from the seeded 2000 ml volume of buffer water. An automatic pipetter with sterile syringe and tubing provided fast and accurate inoculations. Constant agitation of the 2000 ml volume kept the FC population well distributed through the inoculation process. The saturation volume of buffer water previously added to the sediment samples had been calculated to allow for the 10 ml inoculating volume.

5. Samples were sealed and agitated to distribute the bacteria.

E. Iced Storage of Samples

Immediately following inoculation sample bags were placed directly on top of ice in ice chests for storage. Melt water was drained away.

F. Sample Analyses

Following each storage period the appropriate 10 replicate sediment samples and the glass beam sample for that period were examined to determine the FC density. FC densities were determined with the multiple fermentation tube technique (also called most probable number method or MPN) as outlined in Standard Methods (1975). Prior to analyses 100 ml of sterile buffer water was added to each sample bag; the bags were resealed and vigorously shaken producing a pipettable sediment-water mixture with a 2:1 dilution ratio. Standard MPN analyses for FC followed.

III. FC SURVIVAL TEST RESULTS AND CONCLUSION

Densities of FC measured in the test sediments and test glass beads are listed in Table A-3. Inoculation densities were approximately one-half order of magnitude higher than desired, but survival trend information was obtained.

Mean FC densities in sediments and FC densities in glass beads are plotted in Figure A-2 as functions of iced storage time. Survival of FC in sediments was high; die-off in glass beads was dramatic and apparently logarithmic.

Viable populations of FC survived iced storage in sediments for a period exceeding by 5 or more days that required in Grand Canyon field work. Fluctuations recorded in the FC densities over the storage period were within the normal sensitivity range of MPN analyses. High initial FC densities were not suspected of enhancing survival as competition for available nutrients would have been more intense than in lower density populations. Storage temperatures near 4°C apparently retarded FC metabolism enough to permit maintenance survival. Nutrients available in natural bottom sediments appeared to be critical to prolonged FC survival as bacteria were unable to maintain themselves in the simulated sediments of glass beads.

Table A-3. FC Densities in Sediments Following Iced Storage. Values are thousands of FC/100 ml.

Replications	Storage Period in Days												
	0	1	2	3	5	7	9	11	13	15	17	19	21
1	260	920	220	480	480	340	220	140	340	340	700	480	700
2	280	260	480	280	220	700	340	700	340	340	700	280	280
3	340	460	220	440	480	480	340	158	1080	98	220	480	140
4	980	140	159	340	560	480	700	480	340	480	480	92	220
5	460	460	700	260	158	280	480	220	258	92	700	158	340
6	980	220	1080	340	700	188	158	480	440	220	440	260	220
7	660	158	1080	260	700	188	480	440	700	260	700	220	340
8	700	158	340	700	440	480	260	260	440	260	480	46	98
9	1400	980	280	260	1080	480	700	560	340	480	340	34	16
10	340	460	260	440	1080	188	340	1080	340	350	98	98	340
Mean Density ($\overline{X}$)	640	421	482	380	540	366	401	452	402	292	485	215	269
Glass Beads	140	260	38	4	0.098	0.022	0.026	0.010					

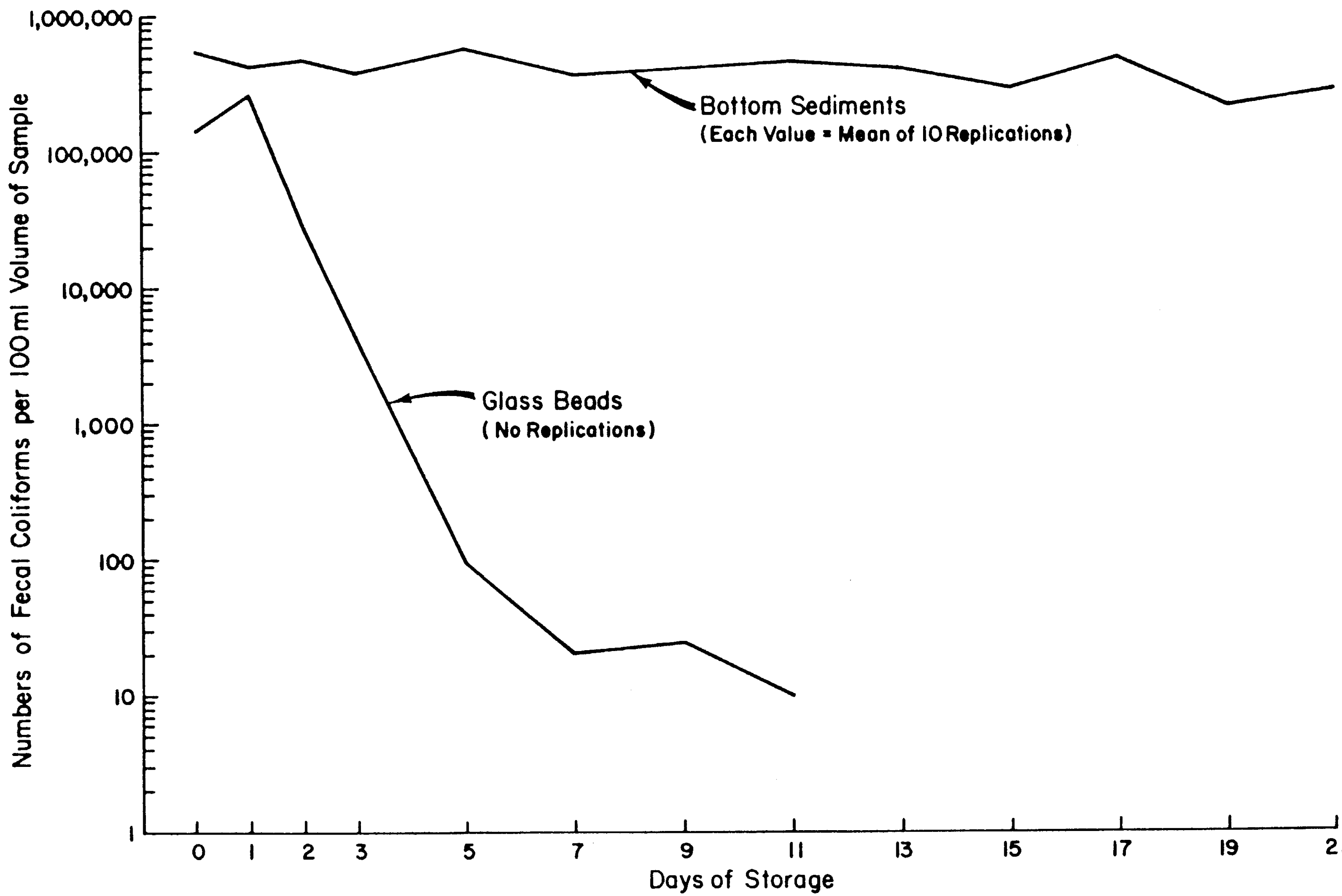


Figure A-2. Mean FC Densities in Sediments and in Glass Beads as Functions of Iced Storage Time.

APPENDIX B. GRAND CANYON DATA SUMMARIES

Table B-1. 1978 Colorado River Data--Six Research Trips.

Station Name	Water Temp $\bar{X}/s$	pH $\bar{X}$	Turbidity $\bar{X}/s$	Surface Water FC/100 ml $\bar{X}/s$	Surface Water log FC* $\bar{X}/s$	Surface Water FS/100 ml $\bar{X}/s$	Surface Water log FS* $\bar{X}/s$	Bottom Sediment FC/100 ml $\bar{X}/s$	Bottom Sediment log FC* $\bar{X}/s$
Lees Ferry	11.7/2.2	7.7	8.0/6.3	< 1	.13/.21	9.0/7.1	.94/.34	120.8/138.3	1.72/.79
Below Paria	10.2/1.3	8.0	5.2/3.9	< 1	.10/.25	20.0/0.0	1.3/0.0		
Navajo Bridge	10.7/1.0	8.0	5.0/2.1	< 1	.04/.11	1.0/0.0	.30/0.0		
Above Badger	10.7/1.9	8.1	6.3/5.9	< 1	.10/.16			139.5/163.5	1.72/.81
Above House Rock	10.2/1.0	8.2	8.4/7.1	< 1	.10/.16			11.0/0.0	1.08/0.0
River at Cave Springs	11.2/1.9	8.2	10.5/7.9	0.0/0.0	0.0/0.0				
River at Vasey's	11.7/1.2	8.0	4.8/3.8	< 1	.18/.21				
Redwall	10.3/1.0	8.0	6.0/2.4	1.0/1.5	.20/.31			27.2/16.7	1.35/.39
Buckfarm	11.0/1.2	8.1	9.5/6.0	1.0/0.9	.26/.19				
Nankoweep Camp	11.2/1.2	8.2	12.6/7.7	< 1	.15/.16	110.7/135.9	1.78/.63	2727.3/4368.1	2.73/1.03
Above Little Colorado	10.8/1.1	8.3	8.6/4.4	1.6/2.1	.31/.33				
Below Little Colorado	11.5/1.0	8.2	8.0/3.5	1.2/1.5	.25/.30	23.0/0.0	1.38/0.0		
Tanner	12.0/1.0	8.1	11.5/7.6	2.4/2.5	.40/.39	18.0/0.0	1.28/0.0	416.0/394.4	2.43/.49
Unkar	12.0/1.0	8.2	9.7/8.4	2.3/3.3	.33/.41	417.8/592.7	2.18/.80	466.0/756.2	2.26/.63
Above Clear Creek	12.0/0.9	8.1	41.4/48.3	4.3/6.9	.48/.49	28.0/0.0	1.46/0.0	27.0/0.0	1.45/0.0
Above Bright Angel	12.3/1.0	8.1	18.6/10.4	5.4/11.0	.44/.55	34.0/34.4	1.39/.46	5056.2/10596.3	2.44/1.36
Below Bright Angel	12.3/1.5	8.2	52.6/53.5	10.6/17.1	.73/.59	81.3/89.6	1.71/.54	12850.0/15768.5	3.81/.81
Monument Camp	11.7/1.0	8.2	24.3/37.3	4.3/3.7	.64/.30	26.3/19.0	1.34/.39	624.8/890.0	2.45/.63
Above Boucher	13.3/2.3	8.3	19.8/29.0	< 1	.18/.21	99.5/98.3	1.86/.52		
Above Crystal	12.5/0.5	8.4	25.4/27.7	1.2/1.5	.27/.26			79.0/0.0	1.90/0.0
Tuna	13.0/1.2	8.3	22.0/26.4	1.7/1.6	.35/.30				
Above Shinumo	13.2/0.8	8.1	20.4/21.1	1.2/1.2	.28/.25	258.0/0.0	2.41/0.0	128.8/280.0	1.38/.77
Below Shinumo	13.5/0.6	8.1	20.5/31.9	1.2/1.6	.26/.29	200.0/0.0	2.30/0.0		
Above Elves	13.0/1.2	8.2	33.7/42.0	2.3/2.3	.41/.36				
Below Elves	13.2/1.5	8.2	22.0/25.5	1.0/1.1	.25/.23				
Above Stone	14.4/0.9	8.2	34.8/36.5	2.3/3.4	.34/.43	54.0/0.0	1.74/0.0		
Below Stone	13.5/1.4	8.3	29.3/35.3	< 1	.20/.25	24.0/0.0	1.40/0.0	49.2/61.7	1.22/.81
Above Tapeats	13.8/0.8	8.3	16.8/17.7	2.3/2.5	.42/.32	1021.7/1730.7	1.99/1.33		

Table B-1.--continued.

Station Name	Water Temp $\overline{X}/s$	pH $\overline{X}$	Turbidity $\overline{X}/s$	Surface Water FC/100 ml $\overline{X}/s$	Surface Water log FC* $\overline{X}/s$	Surface Water FS/100 ml $\overline{X}/s$	Surface Water log FS* $\overline{X}/s$	Bottom Sediment FC/100 ml $\overline{X}/s$	Bottom Sediment log FC* $\overline{X}/s$
Above Deer	13.6/1.1	8.0	11.3/11.3	1.2/2.2	.22/.34			8.0/0.0	0.95/0.0
Below Deer	13.5/1.3	8.4	9.3/7.6	< 1	.15/.18				
Above Kanab	14.2/1.2	8.2	14.8/16.9	< 1	.10/.16			462.0/397.6	2.49/.50
Below Kanab	14.5/0.8	8.3	10.6/11.0	1.5/2.7	.25/.35				
Below Matkatimiba	14.8/0.5	8.3	6.8/3.4	1.5/2.4	.27/.37				
Above Havasu	14.7/0.6	8.2	19.5/26.5	3.5/5.2	.42/.52	18.0/0.0	1.28/0.0		
Below Havasu 1	15.7/1.9	8.4	16.5/12.6	2.5/1.6	.48/.28				
Below Havasu 2	14.2/0.8	8.3	17.3/12.9	< 1	.20/.16				
Below Havasu 3	14.2/0.8	8.3	18.3/13.3	1.0/1.1	.25/.23	29.5/24.7	1.40/.40		
Tuckup	14.8/1.2	8.4	6.6/4.7	1.8/2.2	.34/.35	11.0/0.0	1.08/0.0		
National Camp	14.4/1.0	8.3	19.1/15.4	5.0/11.1	.39/.54	116.0/0.0	2.07/0.0	805.6/949.5	2.48/.92
Whitmore	15.5/1.3	8.3	11.3/5.3	< 1	.06/.13			258.5/442.1	1.72/1.03
193 Mile	15.2/1.5	8.3	21.8/18.4	< 1	.15/.16			79.0/0.0	1.90/0.0
205 Mile	14.8/1.5	8.2	38.2/37.2	4.7/5.4	.57/.45				
Granite Park	15.2/1.3	8.2	41.8/40.3	8.8/6.7	.81/.56			1058.6/1229.9	2.60/.78
River at Granite Spring	15.5/1.4	8.3	44.4/39.0	1.5/2.3	.27/.34	128.0/0.0	2.11/0.0		
Above Diamond	15.6/1.7	8.0	40.3/43.7	28.2/51.5	.94/.76	6.0/0.0	.85/0.0	481.2/947.9	1.89/.96
Below Diamond	16.2/2.4	8.0	26.2/21.0	12.2/12.4	.88/.60				
Time Series (N)	12.7/2.1	8.2 (58)	20.5/25.2 (133)	11.4/95.1 (218)	.34/.46 (218)	481.3/1311.7 (46)	1.97/.74 (46)		
All Observations (N)	12.9/2.1	8.2 (153)	19.7/24.6 (360)	5.8/58.2 (424)	.32/.40 (424)	339.0/1032.1 (85)	1.80/.72 (85)	1068.6/3806.4 (83)	2.04/.93 (83)

$$*\log \overline{X} = \frac{\Sigma \log \text{Individual Observations}}{N}$$

Table B-2. 1979 Colorado River Data--Two Research Trips. Data* shown are individual sample observations.

Site Name	Water Temp °C		Turbidity FTU		Surface Water FC/100 ml		Bottom Sediment FC/100 ml	
	Trip 1	Trip 2	Trip 1	Trip 2	Trip 1	Trip 2	Trip 1	Trip 2
Lees Ferry	12	10	10	3	2	48	6000	2720
Redwall	10		3		0		0	
Above Little Colorado	11	9		20	0	2		
Below Little Colorado	11	9	4	23	1	1		
Unkar	12	10	5	40	0	3	0	420
Above Bright Angel	13	11	5	40	4	0	360	180
Above Shinumo	13	10	5	22	1	0	360	230
Below Stone	13	12	5	15	0	0	0	80
Below Havasu 3	15	12	8	30	1	6		
National Camp	15	13	7	28	100	10	160	460

*Individual sample observations rather than seasonal means are shown for each 1979 station; the sample populations do not warrant calculation of means and standard deviations for each station.

Table B-3. 1979 Colorado River Trip and Season Data Summaries.

Sample Population	Water Temp °C	Turbidity FTU	Surface Water FC/100 ml	Surface Water Log FC*	Bottom Sediments FC/100 ml	Bottom Sediments Log FC*
	$\overline{X}$/s	$\overline{X}$/s	$\overline{X}$/s	$\overline{X}$/s	$\overline{X}$/s	$\overline{X}$/s
Time Series (N)	11.4/2.5 (51)	18.0/32.4 (50)	3.9/14.2 (51)	0.29/0.44 (51)		
All Observations (N)	11.6/2.6 (73)	16.9/28.6 (72)	6.5/18.7 (72)	0.39/0.52 (73)	767/1661 (14)	1.71/1.40 (14)
Trip 1 (N)					983/2218 (7)	1.59/1.56 (7)
Trip 2 (N)					551/974 (7)	1.84/1.34 (7)

$$*\text{Log } \overline{X} = \frac{\Sigma \text{ Log Individual Observations}}{N}$$

Table B-4. 1978 Tributary Data--Six Research Trips.

Site Name	Water Temp $\bar{X}$/s	pH $\bar{X}$	Turbidity $\bar{X}$/s	Surface Water FC/100 ml $\bar{X}$/s	Surface Water log FC* $\bar{X}$/s	Surface Water FS/100 ml $\bar{X}$/s	Surface Water log FS* $\bar{X}$/s	Bottom Sediment FC/100 ml $\bar{X}$/s	Bottom Sediment log FC* $\bar{X}$/s
Paria River	24.6/2.9	8.5	401.0/1267.4	15.5/25.3	0.94/0.90			2685/2263	3.16/0.65
Vasey's Spring	17.2/2.2	8.6	3.4/2.7	1.2/1.94	0.12/0.29				
Nankoweep Creek	24.4/3.6	8.6	6.2/3.3	1.0/1.55	0.29/0.57			2604/2546	3.07/0.77
Little Colorado River	22.2/5.2	8.0	11.0/8.2	1.3/2.80	0.1/0.35			766/1380	1.87/1.34
Clear Creek	20.2/3.0	8.7	7.4/7.1	5.0/10.81	0.29/0.57			10907/18269	3.14/1.22
Bright Angel Creek	18.8/3.5	8.8	15.5/19.7	15.4/15.50	0.95/0.61	76/45.3	1.8/0.41	6691/14149	2.62/1.39
Garden Creek	20.8/4.8	8.4	3.4/1.9	18.5/36.56	0.52/0.41	246/180	2.29/0.33	1140/1736	2.55/0.76
Monument Creek	25.8/4.3	7.8	7.0/7.8	1.2/2.68	0.16/0.35			2882/4623	2.58/1.20
Hermit Creek	23.0/2.4	8.4	5.5/4.7	139.5/323.62	1.07/0.99			11173/18555	3.31/1.05
Upper Hermit	19.0/1.9	8.4	3.4/4.0	3.6/3.13	0.44/0.35			4700/7781	2.91/1.10
Middle Hermit	19.2/1.8	8.4	6.4/7.5	64.2/121.60	0.9/1.08				
Lower Hermit	20.4/1.1	8.4	6.3/4.3	3.8/5.26	0.38/0.46			14992/16131	3.37/1.36
Boucher Creek	29.8/4.5	8.2	2.6/2.5	0.2/0.41	0.0/0.0			163/145	2.07/0.37
Crystal Creek	26.3/6.2	8.5	3.0/5.7	0.3/0.52	0.0/0.0			84.3/137.9	1.41/0.77
Shinumo Creek	18.4/3.6	8.6	4.8/3.6	2.2/1.94	0.36/0.32			1656/2437	2.24/1.27
Upper Elves Chasm	17.6/3.8	8.5	4.0/3.0	26.2/47.8	0.76/0.89			1518/2000	2.51/1.15
Lower Elves Chasm	20.0/1.4	8.5	4.4/3.2	41.4/77.05	1.05/0.74				
Stone Creek	24.3/3.8	8.5	4.2/3.0	2.8/4.02	0.22/0.42			1127/1219	2.55/1.06
Tapeats Creek	14.2/1.9	8.6	9.3/14.5	0.7/1.21	0.08/0.19			1402/1555	2.52/1.03
Upper Deer Creek	15.8/1.9	8.5	1.3/1.0	4.5/4.68	0.5/0.46			9644/18882	2.89/1.47
Lower Deer Creek	15.5/2.2	8.7	6.3/5.9	2.8/2.71	0.31/0.37			1266/1522	2.37/1.24
Kanab Creek	23.0/3.7	8.3	12.0/11.4	4.3/3.78	0.48/0.44			8162/19517	2.55/1.11
Olo Creek	24.6/4.6	8.5	12.0/6.8	31.6/39.02	0.94/0.93			2933/2558	2.81/1.35
Matkatamiba	24.3/4.5	8.1	2.3/0.6	0.8/1.17	0.25/0.62			1523/2203	2.70/0.89
Upper Havasu	20.7/1.9	8.4	3.7/2.9	13.2/5.95	1.09/0.16			4292/7156	2.54/1.52
Middle Havasu	21.2/2.2	8.4	3.2/3.5	8.0/4.34	0.81/0.41			5024/7149	2.89/1.34
Lower Havasu	21.2/1.7	8.4	1.6/1.4	6.8/3.54	0.76/0.38				
National Creek	24.2/4.5	8.0	2.4/2.3	1.2/2.17	0.14/0.31				
Fern Glen	21.2/3.6	7.6	0.6/0.0	1.4/3.13	0.17/0.38			146/178	1.85/0.61

Table B-4.--continued.

Site Name	Water Temp	pH	Turbidity	Surface Water FC/100 ml	Surface Water log FC*	Surface Water FS/100 ml	Surface Water log FS*	Bottom Sediment FC/100 ml	Bottom Sediment log FC*
	$\bar{X}$/s	$\bar{X}$	$\bar{X}$/s	$\bar{X}$/s	$\bar{X}$/s	$\bar{X}$/s	$\bar{X}$/s	$\bar{X}$/s	$\bar{X}$/s
Mohawk Creek	22.3/4.3	8.3	5.4/4.8	3.2/4.87	0.35/0.49				
Pumpkin	26.3/4.9	6.8	33.0/12.0	1.2/3.86	0.14/0.35				
Three Springs	25.8/2.1	8.3	7.6/7.8	54.2/130.2	0.52/1.00				
Diamond Creek	22.0/1.7	8.3	37.4/37.4	117.4/213.6	1.28/0.99			11470/19270	3.11/1.19
All Stations	21.6/4.7	8.3	24.0/201.8						

$$\log \bar{X} = \frac{\Sigma \text{ Log Individual Observations}}{N}$$

Table B-5. 1979 Tributary Data--Two Research Trips. Data* shown are individual sample observations.

Site Name	Water Temp °C		Turbidity FTU		Surface Water FC/100 ml		Bottom Sediment FC/100 ml	
	Trip 1	Trip 2	Trip 1	Trip 2	Trip 1	Trip 2	Trip 1	Trip 2
Little Colorado River	20	22	3	40	0	0	160	860
Bright Angel Creek	23	25	1	31	7	7	8400	44,000
Hermit at River	22	22	4	32	2	3	44,000	420
Upper Hermit	20	20	2	30	0	1		
Middle Hermit	20	21	3	30	4	3	44,000	560
Lower Hermit	22	22	3	20	1	20		
Shinumo Creek	16	25	3	20	1	1		
Upper Elves Chasm	18	20	5	4	8	4810	8400	9200
Lower Deer Creek	14	11	4	5	2	2	160	180
Kanab Creek	25	26	9	15	1	7		
Matkatamiba	27	26	2	20	10	30		
Middle Havasu	22	21	5	12	9	510	600	1860
Lower Havasu	22	22	4	12	10	530		

*Individual sample observations rather than seasonal means are shown for each 1979 station; the sample populations do not warrant calculation of means and standard deviations for each station.

Table B-6. 1979 Tributary Trip and Season Data Summaries.

Sample Population (All Tributaries)	Water Temp °C	Turbidity FTU	Surface Water FC/100 ml	Surface Water log FC*	Bottom Sediments FC/100 ml	Bottom Sediments log FC*
	$\overline{X}/s$	$\overline{X}/s$	$\overline{X}/s$	$\overline{X}/s$	$\overline{X}/s$	$\overline{X}/s$
Trip 1	20.8/3.48	3.7/1.97	4.2/4.0	0.58/0.39	15102/20070	3.48/1.07
(N)	(13)	(13)	(13)	(13)	(13)	(13)
Trip 2	21.8/3.88	20.8/11.14	456/1322	1.23/1.13	8154/16124	3.21/0.83
(N)	(13)	(13)	(13)	(13)	(13)	(13)
Season	21.3/3.6	12.3/11.7	230/945	0.90/0.89	11628/17858	3.34/0.93
(N)	(26)	(26)	(26)	(26)	(26)	(26)

$$*\log \overline{X} = \frac{\Sigma \text{ Log Individual Observations}}{N}$$

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APPENDICES